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of Engineers®  
Engineer Research and  
Development Center

### *Wetlands Research Program*

## A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Prairie Potholes

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FHWA



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## PREFACE

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# 1 Introduction

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## Background

The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods used collectively to develop functional indices and apply them to the assessment of wetlands. The HGM approach was initially intended to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review to analyze project alternatives, minimize impacts, assess unavoidable project impacts, determine mitigation requirements, and monitor the success of compensatory mitigation. However, a variety of other potential applications for the approach have been identified including: determining minimal effects under the Food Security Act, designing mitigation projects, providing wetland restoration design standards and aiding in wetlands management.

In the HGM Approach, the functional indices and assessment protocols used to assess a specific type of wetland in a specific geographic region are published in a document referred to as a Regional Guidebook. Guidelines for developing Regional Guidebooks were published in the National Action Plan (National Interagency Implementation Team 1996) developed cooperatively by the U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency (USEPA), Natural Resources Conservation Service (NRCS), Federal Highways Administration (FHWA), and U.S. Fish and Wildlife Service (USFWS). The Action Plan, available online at <http://www.epa.gov/OWOW/wetlands/science/hgm.html>, outlines a strategy for developing Regional Guidebooks throughout the United States, provides guidelines and an explicit set of tasks required to develop a Regional Guidebook under the HGM Approach, and solicits the cooperation and participation of Federal, State, and local agencies, academia, and the private sector.

In the context of the current set of federal rules, regulations and policies, the Natural Resources Conservation Service (NRCS) has the mandate to assist and cooperate with federal, state and local agencies to restore and maintain the physical, chemical and biological integrity of the nation's waters. NRCS responsibilities are especially important in the agricultural environments of our nation. In working to achieve the statutory and policy goals set before it, NRCS often has the need to assess past, present, or potential impacts to wetlands that are associated with agricultural operations. The scope and direction of NRCS activities and responsibilities on agricultural lands are described, in part, in the Food Security Act of 1985, as amended by the Food, Agriculture, Conservation and Trade Act of 1990, the 1993 President's Federal Wetland Plan, 1996 Farm Bill, Federal Agricultural Improvement and Reform Act of 1996, 2002 Farm Bill, The Farm Security and Rural Investment Act of 2002 and the third edition of the *National Food Security Act Manual* (NFSAM). For example, the current versions of the NFSAM require that NRCS assess wetland functions as part of the minimal effect procedures. Assessment of wetland functions is also a key step during NRCS analyses of wetland mitigation plans, and as a part of NRCS evaluation of restoration efforts in degraded wetlands. This Guidebook provides an additional tool for NRCS, COE and others to conserve, restore and manage prairie pothole wetlands.

The objectives of this Regional Guidebook are to:

- (1) Characterize temporary and seasonal prairie pothole wetland ecosystems based on the factors that influence wetland function including the hydrogeomorphic classification factors identified by Brinson (1993).
- (2) Present the rationale used to select functions for this depressional regional wetland subclass.
- (3) Present the rationale used to select assessment variables and metrics.
- (4) Present the rationale used to develop assessment models.
- (5) Provide data from reference wetlands and document its use in the calibrating of assessment models.
- (6) Describe the protocols for the assessment of wetland functions in temporary and seasonal prairie pothole wetland ecosystems throughout the Prairie Pothole Region (PPR).

The document is organized in the following manner. Chapter 1 provides the background, objectives, and organization of the document. Chapter 2 provides a brief overview of the components and application of the HGM Approach. Chapter 3 characterizes the temporary and seasonal prairie pothole wetland subclass in the PPR included in this guidebook. Chapter 4 discusses the variables used in the assessment models, wetland functions, and functional indices. The discussion includes:

- (1) A definition, description, and measurement techniques of model variables and variable sub-index graphs or condition categories.
- (2) A definition of the function and a quantitative, independent measure of the function for the purposes of validation.
- (3) A rationale for choosing the function.
- (4) A description of the wetland ecosystem and landscape characteristics that influence the function.
- (5) A brief description of variables used to represent these characteristics in the assessment model.
- (6) A Functional Capacity Index (FCI) model and a discussion of how model variables were combined to derive the functional index.

Chapter 5 outlines the steps and protocols that are necessary to conduct an assessment including field forms and other information. Appendix A is a glossary of terms, Appendix B provides spreadsheets for analyzing the data collected during the assessment, and Appendix C provides the information necessary to access the reference wetland data and spatial information collected during the project. Although it is possible to begin the assessment process immediately using the information in Chapter 5, we advise that potential users first familiarize themselves with the information in Chapters 2-4.

## 2 Overview of the Hydrogeomorphic Approach

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### Development and Application Phases

The Hydrogeomorphic Approach (HGMA) to Wetland Functional Assessment is a collection of concepts and methods that are used to develop and apply functional indices to the assessment of wetlands (Smith et al. 1995). The HGMA includes four integral components: 1) HGM Classification, 2) Reference wetlands, 3) Assessment variables and assessment models from which functional indices are derived, and 4) Application protocols. The four components of the HGMA are integrated into a Regional, Subclass-specific Guidebook, like this document.

In the Development Phase of the HGMA, research scientists and regulatory managers work cooperatively to select a list of functions and indicators of function that will best represent the functional range of variation among wetlands of the subclass and region. Data are gathered by an Assessment Team (A-Team) from an array of wetlands that represent that range of variation and establish a data set of Reference Wetlands. The assessment models and data are combined along with field protocols and methods for analysis to formulate the Regional Guidebook. The end-users then employ the Regional Guidebook during the Application Phase to conduct HGM functional assessments on project wetlands. Each of these components of the HGM Approach is discussed briefly below. More extensive discussions of these topics can be found in Brinson (1993, 1995a, 1995b), Brinson et al. (1995, 1998), Hauer and Smith (1998), Smith et al. (1995), Smith (2001), Smith and Wakeley (2001), and Wakeley and Smith (2001).

The task of the A-Team is to develop and integrate the classification, reference wetland, assessment variables, models, and application protocol components of the HGM Approach into a Regional Guidebook (Figure 1). In developing a Regional Guidebook, the team completes the tasks outlined in the National Action Plan (National Interagency Implementation Team 1996). These tasks include:

#### Task 1: Organize the A-Team

- A. Identify team members
- B. Train team in the HGM Approach

#### Task 2: Select and Characterize Regional Wetland Subclass

- A. Identify/prioritize regional wetland subclasses
- B. Select regional wetland subclass and define reference domain
- C. Initiate literature review
- D. Develop preliminary characterization of regional wetland subclass
- E. Identify and define wetland functions

#### Task 3: Select Assessment Variables and Metrics and Construct Conceptual Assessment Models

- A. Review existing assessment models

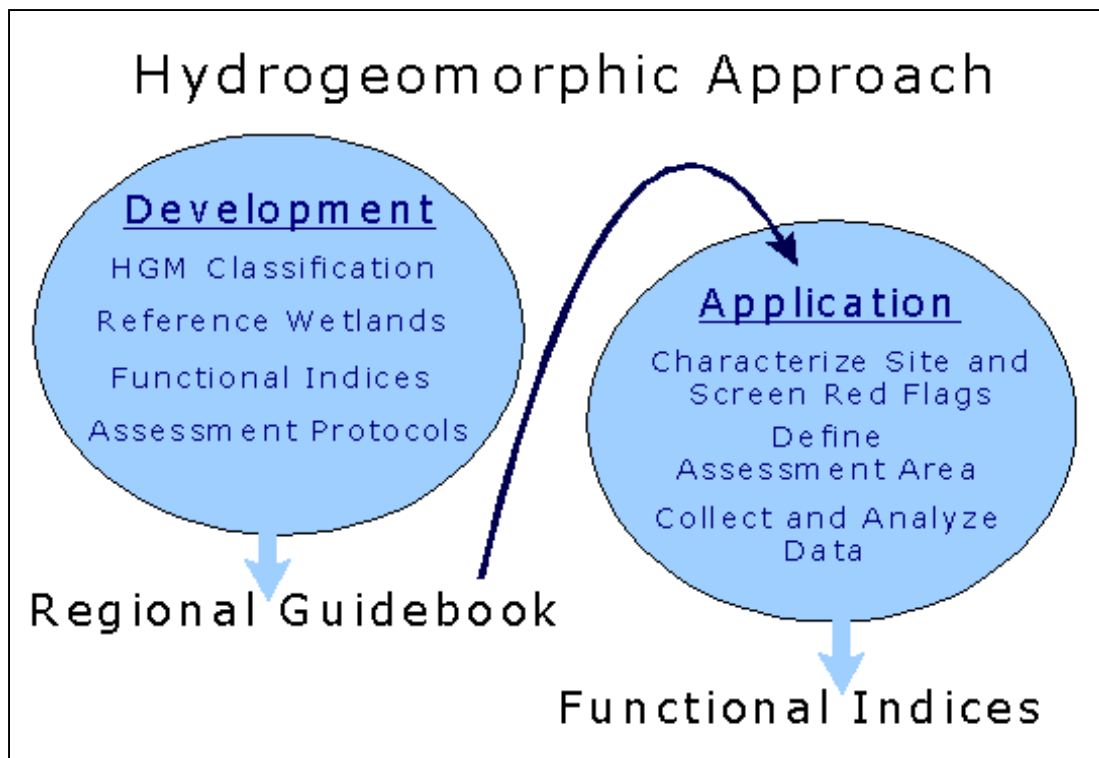


Figure 1. Schematic of development and application phases of the HGM approach.

- B. Identify assessment variables and metrics
- C. Define initial relationship between assessment variables and functional capacity
- D. Construct conceptual assessment models for deriving functional capacity indices
- E. Complete Pre-calibrated Draft Regional Guidebook (PDRG)

**Task 4: Conduct Peer Review of Pre-calibrated Draft Regional Guidebook**

- A. Distribute PDRG to peer reviewers
- B. Conduct interdisciplinary, interagency workshop of PDRG
- C. Revise PDRG to reflect peer review recommendations
- D. Distribute revised PDRG to peer reviewers for comment
- E. Incorporate final comments from peer reviewers on revisions into the PDRG

**Task 5: Identify and Collect Data From Reference Wetlands**

- A. Identify reference wetland field sites
- B. Collect data from reference wetland field sites
- C. Analyze reference wetland data

**Task 6: Calibrate and Field Test Assessment Models**

- A. Calibrate assessment variables using reference wetland data
- B. Verify and validate (optional) assessment models
- C. Field test assessment models for repeatability and accuracy

- B. Revise PDRG based on calibration, verification, validation (optional), and field testing results into a Calibrated Draft Regional Guidebook (CDRG)

**Task 7: Conduct Peer Review and Field Test of Calibrated Draft Regional Guidebook**

- A. Distribute CDRG to peer reviewers
- B. Field test CDRG
- C. Revise CDRG to reflect peer review and field test recommendations
- D. Distribute CDRG to peer reviewers for final comment on revisions
- E. Incorporate peer reviewers' final comments on revisions
- C. Publish Operational Draft Regional Guidebook (ODRG)

**Task 8: Technology Transfer**

- A. Train end users in the use of the ODRG
- B. Provide continuing technical assistance to end users of the ODRG

This Guidebook has been developed by NRCS and the USACE as one component of the National Action Plan and in response to NRCS and USACE needs for a consistent and scientifically based assessment procedure for assessment of functions of wetlands in the Prairie Pothole Region. Specifically, this guidebook addresses functions of the temporary and seasonal wetlands in the prairie pothole region (PPR) of the Midwest and the Northern Plains. Throughout the development and completion of this Guidebook, six teams of wetland experts were integrally involved. Members of the teams are shown below in Table 1.

<b>Table 1. Contributors to the Regional Guidebook.</b>	
<b>Team</b>	<b>Team Members and Affiliation</b>
Guidebook Editors	Michael Whited (NRCS, Wetland Science Institute), Michael Gilbert (Corps of Engineers, Omaha District), Ellis J. Clairain and R. Daniel Smith (Corps of Engineers, Waterways Experiment Station)
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Regional Experts	James LaBaugh (USGS), Daniel Hubbard (SDSU), Mike Anderson (NRCS), Sandra Byrd (NRCS), Harold Kantrud (NPSC), Dennis Magee (Normandeau Assoc.), Arnold van der Valk (University of Iowa), Laura Mazanti (NRCS), James Richardson (NDSU), George Swanson, Lew Cowardin, Ned H. Euliss Jr. (USGS), Loren Smith (Texas Tech Univ.), Milton Weller (Texas A & M Univ.)

1. National Wetland Science Training Cooperative

Initial development of this Guidebook began at a workshop on June 19-21, 1995 in Jamestown, North Dakota. Attendees to the workshop included hydrologists, biogeochemists, soil

scientists, wildlife biologists, and plant ecologists, with extensive knowledge of prairie pothole wetlands, from the public, private, and academic sectors. Based on the results of the workshop, a regional wetland subclass was defined and characterized, a reference domain was defined, wetland functions were selected, model variables were identified, and conceptual assessment models were developed. Subsequently, fieldwork was conducted to collect data from reference wetlands in 1996 and 1997. These data were used to revise and calibrate the conceptual assessment models. A draft version of the Regional Guidebook was then subjected to several rounds of peer review and revised into the *Operational Draft Guidebook* (Lee et al. 1997).

The *Operational Draft Guidebook* (Lee et al. 1997) provided the framework for further reference data collection that occurred throughout the PPR in 1998 and 1999. The data was collected by 2 teams: a team from the U.S. Geological Survey Northern Prairie Wildlife Research Center under the direction of Ned Euliss and Robert Gleason; and another team consisting primarily of NRCS Northern Plains Wetland Specialists with assistance from state and local offices of the NRCS, COE, and USFWS personnel (NRCS Jamestown Team). The USGS team focused on collecting data from seasonally inundated natural (reference standard) and restored wetlands throughout the region, the NRCS team focused on collecting reference data from agriculturally impacted wetlands in the region. These reference data were then combined to form a reference data set of 180 prairie potholes throughout the reference domain.

During the Application Phase of the HGM Approach, the assessment variables, models, and protocols are used to assess wetland functions. This involves two steps. The first is to apply the assessment protocols outlined in the Regional Guidebook to complete the following tasks.

- a. Define assessment objectives.
- b. Characterize the project site.
- c. Screen for red flags.
- d. Define the Wetland Assessment Area.
- e. Collect field data.
- f. Analyze field data.

The second step involves applying the results of the assessment at various decision-making points in the permit review sequence, such as alternatives analysis, minimization, assessment of unavoidable impacts, determination of compensatory mitigation, design and monitoring of mitigation, comparison of wetland management alternatives or results, determination of restoration potential, or identification of acquisition or mitigation sites.

## Hydrogeomorphic Classification

Wetland ecosystems share a number of characteristics including relatively long periods of inundation and / or saturation, hydrophytic vegetation, and hydric soils. Despite these common features, wetlands exist under a wide range of climatic, geologic, and physiographic situations and exhibit a wide variety of physical, chemical, and biological characteristics (Ferren et al. 1996a, Cowardin et al. 1979, Mitch and Gosselink 1993). This variability presents a challenge to the development of assessment methods that are both accurate, in the sense that the method detects significant change in function, and practical, in the sense the method can be carried out in the relatively short time frame that is generally available for conducting assessments. “Generic” wetland assessment methods, designed to assess multiple types of wetlands, lack the level of detail necessary to detect significant changes in function. Consequently, one way to achieve an

appropriate level of resolution within a rapid time frame is to employ an approach that focuses on a subset of wetlands, thereby reducing the level of variability exhibited by the wetlands being considered (Smith et al. 1995).

The HGM Classification (Brinson 1993) was developed specifically to accomplish this task. It identifies groups of wetlands that function similarly using three criteria that fundamentally influence how wetlands function. These criteria are geomorphic setting, water source, and hydrodynamics. Geomorphic setting refers to the landform in which the wetland occurs, its geologic evolution, and its topographic position in the landscape. Water source refers to the primary source of the water entering the wetland. The three primary water sources are precipitation, overbank surface flow, or ground water. Hydrodynamics refers to the level of energy and the direction that water moves into and through the wetland.

Based on these three classification criteria any number of “functional” wetland groups can be identified at different spatial or temporal scales. For example, at a broad continental scale Brinson (1993) identified five hydrogeomorphic wetland classes. These were later expanded to the seven classes described in Table 2 (after Smith et al. 1995).

<b>Table 2.</b> <b>Hydrogeomorphic Wetland Classes</b>	
HGM Wetland Class	Definition
Depression	Depression wetlands occur in topographic depressions (i.e., closed elevation contours) that allow the accumulation of surface water. Depression wetlands may have any combination of inlets and outlets or lack them completely. Potential water sources are precipitation, overland flow, streams, or groundwater/ interflow from adjacent uplands. The predominant direction of flow is from the higher elevations toward the center of the depression. The predominant hydrodynamics are vertical fluctuations that range from diurnal to seasonal. Depression wetlands may lose water through evapotranspiration, intermittent or perennial outlets, or recharge to groundwater. Prairie potholes, playa lakes, and cypress domes are common examples of depression wetlands.
Tidal Fringe	Tidal fringe wetlands occur along coasts and estuaries and are under the influence of sea level. They intergrade landward with riverine wetlands where tidal current diminishes and river flow becomes the dominant water source. Additional water sources may be groundwater discharge and precipitation. The interface between the tidal fringe and riverine classes is where bidirectional flows from tides dominate over unidirectional ones controlled by floodplain slope of riverine wetlands. Because tidal fringe wetlands are frequently flooded and water table elevations are controlled mainly by sea surface elevation, tidal fringe wetlands seldom dry for significant periods. Tidal fringe wetlands lose water by tidal exchange, by overland flow to tidal creek channels, and by evapotranspiration. Organic matter normally accumulates in higher elevation marsh areas where flooding is less frequent and the wetlands are isolated from shoreline wave erosion by intervening areas of low marsh. <i>Spartina alterniflora</i> salt marshes are a common example of tidal fringe wetlands.
Lacustrine Fringe	Lacustrine fringe wetlands are adjacent to lakes where the water elevation of the lake maintains the water table in the wetland. In some cases, these wetlands consist of a floating mat attached to land. Additional sources of water are precipitation and groundwater discharge, the latter dominating where lacustrine fringe wetlands intergrade with uplands or slope wetlands. Surface water flow is bidirectional, usually controlled by water level fluctuations resulting from wind or seiche. Lacustrine wetlands lose water by flow returning to the lake after flooding and evapotranspiration. Organic matter may accumulate in areas sufficiently protected from shoreline wave erosion. Unimpounded marshes bordering the Great Lakes are an example of lacustrine fringe wetlands.

Table 2 (concluded)	
Slope	Slope wetlands are found in association with the discharge of groundwater to the land surface or sites with saturated overland flow with no channel formation. They normally occur on sloping land ranging from slight to steep. The predominant source of water is groundwater or interflow discharging at the land surface. Precipitation is often a secondary contributing source of water. Hydrodynamics are dominated by downslope unidirectional water flow. Slope wetlands can occur in nearly flat landscapes if groundwater discharge is a dominant source to the wetland surface. Slope wetlands lose water primarily by saturated subsurface flows, surface flows, and evapotranspiration. Slope wetlands may develop channels, but the channels serve only to convey water away from the slope wetland. Slope wetlands are distinguished from depression wetlands by the lack of a closed topographic depression and the predominance of the groundwater/interflow water source. Fens are a common example of slope wetlands.
Mineral Soil Flats	Mineral soil flats are most common on interfluvies, extensive relic lake bottoms, or large alluvial terraces where the main source of water is precipitation. They receive virtually no groundwater discharge, which distinguishes them from depressions and slopes. Dominant hydrodynamics are vertical fluctuations. Mineral soil flats lose water by evapotranspiration, overland flow, and seepage to underlying groundwater. They are distinguished from flat non-wetland areas by their poor vertical drainage due to impermeable layers (e.g., hardpans), slow lateral drainage, and low hydraulic gradients. Mineral soil flats that accumulate peat can eventually become organic soil flats. They typically occur in relatively humid climates. Pine flatwoods with hydric soils are an example of mineral soil flat wetlands.
Organic Soil Flats	Organic soil flats, or extensive peatlands, differ from mineral soil flats in part because their elevation and topography are controlled by vertical accretion of organic matter. They occur commonly on flat interfluvies, but may also be located where depressions have become filled with peat to form a relatively large flat surface. Water source is dominated by precipitation, while water loss is by overland flow and seepage to underlying groundwater. They occur in relatively humid climates. Raised bogs share many of these characteristics but may be considered a separate class because of their convex upward form and distinct edaphic conditions for plants. Portions of the Everglades and northern Minnesota peatlands are examples of organic soil flat wetlands.
Riverine	Riverine wetlands occur in floodplains and riparian corridors in association with stream channels. Dominant water sources are overbank flow or backwater from the channel or subsurface hydraulic connections between the stream channel and wetlands. Additional sources may be interflow, overland flow from adjacent uplands, tributary inflow, and precipitation. When overbank flow occurs, surface flows down the floodplain may dominate hydrodynamics. In headwaters, riverine wetlands often intergrade with slope, depression, poorly drained flat wetlands, or uplands as the channel (bed) and bank disappear. Perennial flow is not required. Riverine wetlands lose surface water via the return of floodwater to the channel after flooding and through surface flow to the channel during rainfall events. They lose subsurface water by discharge to the channel, movement to deeper groundwater (for losing streams), and evapotranspiration. Peat may accumulate in off-channel depressions (oxbows) that have become isolated from riverine processes and subjected to long periods of saturation from groundwater sources. Bottomland hardwoods on floodplains are an example of riverine wetlands.

In most cases, the level of variability encompassed by a continental scale hydrogeomorphic class is too great to allow development of assessment models that can be rapidly applied while being sensitive enough to detect changes in function at a level of resolution appropriate for the majority of application needs. For example, at a continental scale, the depression class includes wetlands as diverse as vernal pools in California (Zedler 1987), prairie potholes in the Midwest and Great Plains (Kantrud, Krapu, and Swanson 1989; Hubbard 1988), playa lakes in the High Plains of Texas (Bolen, Smith, and Schramm 1989), kettles in New England (Golet and Larson 1974) and cypress domes in Florida (Kurz and Wagner 1953; Ewel and Odum 1984).

To reduce both inter- and intra-regional variability, the three classification criteria are applied at a smaller regional geographic scale to identify regional wetland subclasses. In many parts of the country, existing wetland classifications can serve as a starting point for identifying regional wetland subclasses (e.g., Ferren et al. 1996a, 1996b; Wharton et al. 1982; Golet and Larson 1974; Stewart and Kantrud 1971). Regional wetland subclasses, like the continental scale wetland classes, are distinguished on the basis of geomorphic setting, water source, and hydrodynamics. In addition, certain ecosystem or landscape characteristics may also be useful for distinguishing regional subclasses in certain areas. For example, regional depression subclasses might be based on water source (i.e., groundwater versus surface water), or the degree of connection between the wetland and other surface waters (i.e., the flow of surface water in or out of the depression through defined channels). In the estuarine fringe class, subclasses could be based on salinity gradients. Regional slope subclasses might be based on the degree of slope, soil type (e.g. mineral or organic), the chemical composition of the source water, or other factors.

Regional riverine subclasses could be based on water source, position in the watershed, stream order, watershed size, channel gradient, or floodplain width. Examples of potential regional subclasses are shown in Table 3 (after Smith et al. 1995; Rheinhardt, Brinson and Farley 1997). Regional Guidebooks include a thorough characterization of the regional wetland subclass in terms of its geomorphic setting, water sources, hydrodynamics, vegetation, soil, and other features that were taken into consideration during the classification process.

<b>Table 3.</b>				
<b>Potential Regional Wetland Subclasses in Relation to Classification Criteria</b>				
<b>Classification Criteria</b>			<b>Potential Regional Wetland Subclasses</b>	
<b>Geomorphic Setting</b>	<b>Dominant Water Source</b>	<b>Dominant Hydrodynamics</b>	<b>Eastern United States</b>	<b>Western United States/Alaska</b>
Depression	Groundwater or interflow	Vertical	Prairie pothole marshes, Carolina bays	California vernal pools
Fringe (tidal)	Ocean	Bidirectional, horizontal	Chesapeake Bay and Gulf of Mexico tidal marshes	San Francisco Bay marshes
Fringe (lacustrine)	Lake	Bidirectional, horizontal	Great Lakes marshes	Flathead Lake marshes
Slope	Groundwater	Unidirectional, horizontal	Fens	Avalanche chutes
Flat (mineral soil)	Precipitation	Vertical	Wet pine flatwoods	Large playas
Flat (organic soil)	Precipitation	Vertical	Peat bogs; portions of Everglades	Peatlands over permafrost
Riverine	Overbank flow from channels	Unidirectional, horizontal	Bottomland hardwood forests	Riparian wetlands

## Reference Wetlands

Reference wetlands are the wetland sites selected to represent the range of variability that occurs in a regional wetland subclass as a result of natural processes and disturbance (e.g., succession, fire, erosion and sedimentation) as well as anthropogenic alterations. The HGM Approach uses reference wetlands for several purposes. First, they provide a tangible, physical representation of wetland ecosystems that can be observed and measured. Second, they establish the range and variability of conditions exhibited by the Regional Wetland Subclass in the reference domain (i.e., the geographic area represented by the reference wetland). Finally, they provide the data necessary for calibrating assessment model variables and functional indices.

The reference domain is the geographic area occupied by the reference wetlands (Smith et al. 1995). Ideally, the geographic extent of the reference domain will mirror the geographic area encompassed by the regional wetland subclass; however, this is not always possible due to time and resource constraints.

The HGM Approach uses reference wetlands for several purposes. First, they establish a basis for defining what constitutes a characteristic and sustainable level of function across the suite of functions selected. Second, they establish the range and variability of conditions exhibited by assessment variables and provide the data necessary for calibrating variables and models. Finally, they provide a tangible, physical representation of wetland ecosystems that can be observed and measured repeatedly.

Reference standard wetlands are the subset of reference wetlands that achieve the highest, sustainable level of functioning across the suite of functions. Generally, they are the least altered wetland sites in the least altered landscapes. By definition all model variable subindices and

functional capacity indices (FCI) are set to 1.0 based on the range of conditions found in reference standard wetlands (Smith et al. 1995). Table 4 outlines the terms used by the HGM Approach in the context of reference wetlands.

<b>Table 4. Reference Wetland Terms and Definitions</b>	
<b>Term</b>	<b>Definition</b>
Reference Domain	The geographic area from which reference wetlands representing the regional wetland subclass are selected (Smith et al. 1995).
Reference Wetlands	A group of wetlands that encompass the known range of variability in the regional wetland subclass resulting from natural processes and human alteration.
Reference Standard Wetlands	The subset of reference wetlands that perform a representative suite of functions at a level that is both sustainable and characteristic of the least human altered wetland sites in the least human altered landscapes. By definition, the functional capacity index for all functions in a reference standard wetland is 1.0.
Reference Standard Wetland Variable Condition	The range of conditions exhibited by assessment variables in reference standard wetlands. By definition, reference standard conditions receive a variable subindex score of 1.0.
Site Potential (Mitigation project context)	The highest level of function possible given local constraints of disturbance history, land use, or other factors. Site potential may be less than or equal to the levels of function in reference standard wetlands of the regional wetland subclass.
Project Target (Mitigation project context)	The level of function identified or negotiated for a restoration or creation project.
Project Standards (Mitigation project context)	Performance criteria and/or specifications used to guide the restoration or creation activities toward the project target. Project standards should specify reasonable contingency measures if the project target is not being achieved.

## Assessment Models and Functional Indices

In the HGMA assessment models are simple representations of functions performed by wetland ecosystems that are constructed and calibrated by the assessment team during the development phase. Assessment models define the relationship between one or more characteristics or processes of the wetland ecosystem and the surrounding landscape, and the functional capacity of a wetland ecosystem. Functional capacity is the ability of a wetland to perform a specific function relative to the ability of reference standard wetlands to perform the same function. Assessment models result in a Functional Capacity Index (FCI) ranging from 0.0 - 1.0. The FCI is a measure of the functional capacity of a wetland relative to reference standard wetlands in the reference domain. Wetlands with an FCI of 1.0 perform the assessed function at a level that is characteristic of reference standard wetlands. A lower FCI indicates that the wetland being assessed is performing a function at a level below the level that is characteristic of reference standard wetlands.

Assessment model variables are ecological quantities that consist of five components (Schneider 1994). These include: (a) a name, (b) a symbol, (c) a metric and a procedure for measurement, (d) metric value (i.e., the numbers, categories, or numerical estimates that are generated by applying the procedural statement (Leibowitz and Hyman 1997)), and (e) units on the appropriate measurement scale. Assessment model variables represent the characteristics of the wetland ecosystem and surrounding landscape that influence the functional capacity of the wetland ecosystem. Model variables can occur in various conditions that correspond to the range of conditions exhibited by reference wetlands in a reference domain. For example, vegetation

species composition can be more or less diverse, ponding can be more or less frequent, and soils can be more or less permeable. Model variables are assigned a sub-index ranging from 0.0-1.0 based on the relationship between that variable condition and functional capacity of sampled wetland ecosystems. When the condition of a variable is similar to a reference standard defined for a reference domain, it is assigned an index of 1.0. As the variable metric value deflects in either direction from the reference standard condition, it is assigned a progressively lower value based upon a defined relationship between metric values and functional capacity.

In addition to defining the relationship among variables and the relationship between variables and functional capacity, variables are combined in an aggregation equation to produce a functional capacity index (FCI) in the assessment model. The FCI is a measure of the functional capacity of a wetland relative to reference standards in the reference domain, and ranges from 0.0-1.0. Wetlands with a functional capacity index of 1.0 exhibit conditions similar to reference standards. The FCI decreases as conditions deviate from reference standards. A wetland ecosystem with an FCI of 0.1 performs the function at a minimal, essentially unmeasurable, level, but retains the potential for recovery. A wetland with a FCI 0.0 does not perform the function, and does not have the potential for recovery, in a practical sense because the change is essentially permanent.

## **Assessment Protocol**

The final component of the HGM Approach is the assessment steps and protocols. The assessment protocol is a defined set of tasks, along with specific instructions, that allows the end user to assess the functions of a particular wetland area using the assessment variables, models, and functional indices in the Regional Guidebook. The first task is characterization of the wetland ecosystem and the surrounding landscape, describing the proposed project and its potential impacts, and identifying the wetland area(s) to be assessed. The second task is collecting the data for assessment variables to run the functional models. The final task is an analysis that involves calculation of functional indices in the context of regulatory, planning or management programs (Smith et al. 1995).

# **3 Characterization of the Temporary and Seasonally Ponded Prairie Pothole Wetland Ecosystems**

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## **Regional Wetland Subclass and Reference Domain**

This Regional Guidebook is designed to assess the functions of depressional, palustrine, herbaceous, temporarily and seasonally ponded wetlands formed in glacial till. The geographic area of interest is commonly referred to as the Prairie Pothole Region (PPR).

The PPR is large and contains waters/wetlands of numerous hydrogeomorphic subclasses. The A-Team was seeking an HGM guidebook that would best serve their needs in a diverse landscape with a variety of anthropogenic disturbances. Prior to collecting, analyzing, and synthesizing data, and developing the draft regional model, the National, Technical, Agency, and A-Teams defined priority wetland subclasses. The most common wetland subclass, which also receives the most pressure for conversion, is small depressional wetlands with temporary and seasonal hydroperiods. About 79 percent of prairie pothole wetlands are less than 0.4 hectare (ha) in size and about 66 percent are less than 0.2 ha in size (Dahl 1990). Most of these are in the regional subclass for which this guidebook is intended. These more temporary types of wetlands are important for waterfowl feeding and courtship, as well as functions such as groundwater recharge and flood storage, and are considered to be under-protected (Hubbard 1988).

Temporary and seasonal wetlands, for the purposes of this guidebook, are classified by the system devised by Stewart and Kantrud (1971). They classify wetland basins in the northern prairie on the basis of the vegetation found in their central or deepest zone. Therefore, temporary and seasonal wetlands in prairie depressional systems are a function of the water depth and duration (van der Valk 1981). The dominant hydrologic inputs to temporary and seasonal prairie pothole wetlands are surface runoff of snowmelt and early spring rains which do not infiltrate into the frozen upland soils. The dominant hydrologic output is evapotranspiration; a secondary output is downward seepage (i.e. recharge). The dominant hydrodynamics are vertical. The complete descriptor of this subclass is: prairie potholes, low permeability substrate, temporary and seasonal hydroperiods, depressions.

There are two important distinctions for use of this guidebook. First, this subclass does not include wetlands developed in coarse textured (i.e. sandy) parent materials (such as glacial outwash) because these wetlands are in a different hydrogeologic setting. Second, this subclass does not include larger wetlands with semi-permanent (or wetter) hydrologic regimes. These wetlands are more likely to be areas of groundwater flow-through or discharge, provide distinct

habitat functions, commonly have more saline tolerant plant communities, and have different basin morphometry and structure.

## Description of the Regional Subclass

### Landscape Setting: Physiographic Divisions

Boundaries of the region have not been precisely defined, but most authors have used or modified the bounds established by Mann (1974) as illustrated in Figure 2. The PPR in the U.S. includes parts of extreme northern Montana, much of eastern South and North Dakota, western Minnesota and the glaciated Des Moines lobe of north central Iowa.

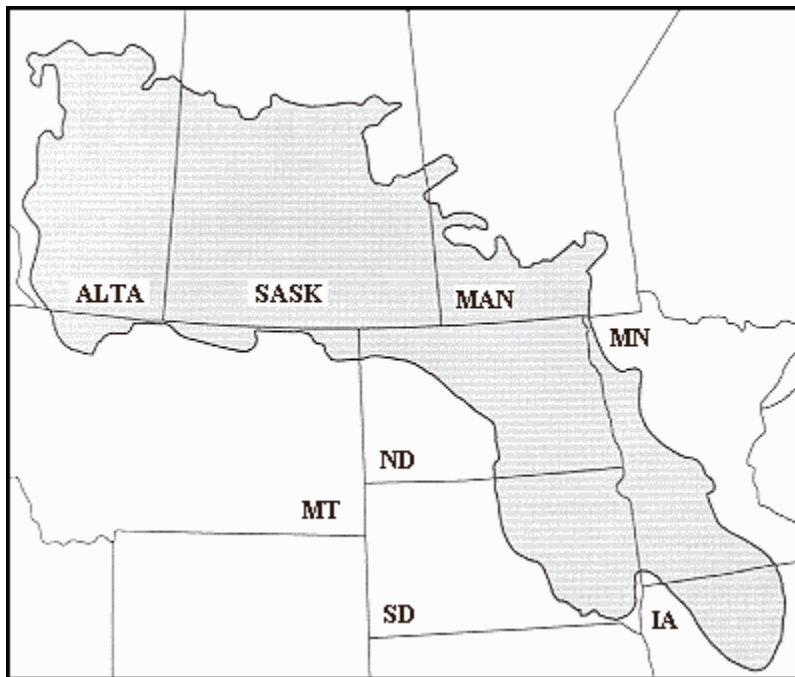


Figure 2. The Prairie Pothole Region of North America (after Mann, 1974).

The PPR has been subdivided into the northern and southern PPR, generally analogous to the break between areas where small grain crops are dominant (northern) and areas where row crops (corn, soybeans) are grown (southern) (Galatowitsch and van der Valk 1994). The southern PPR is in Land Resource Region M and the northern PPR is in Land Resource Region F (United States Department of Agriculture 1981). The southern PPR is warmer and wetter than the northern PPR and the division between northern and southern approximates the boundary between the tall-grass prairie and the mixed-grass prairie. Geomorphologists have traditionally divided the northern grasslands into two large areas called the Great Plains and Central Lowland (Fenneman 1931). The more arid Great Plains supports native grassland that is shorter than that in the moister Central Lowland to the east. The reference domain for this guidebook includes portions of both these areas.

The Great Plains portion of the Prairie Pothole Region contains a single physiographic division, the Missouri Coteau. This division is approximately 52,000 km<sup>2</sup> in area. The Missouri Coteau extends from northeastern Montana through North and South Dakota to the Nebraska border. Generally, it runs parallel to and east of the Missouri River. It consists of hummocky

topography - thus the Canadian French coteau, meaning "little hill." The Coteau is characterized by non-integrated drainage (meaning that ponds and sloughs are not connected to one another and no streams flow through the area). In these areas the glacial deposits are thick, and large-scale glacial stagnation processes predominated, resulting in a hilly, irregular surface with numerous wetlands and lakes.

A gently sloping scarp, several hundred feet high and mostly covered by glacial deposits (referred to collectively as drift), separates the Coteau du Missouri from the lower, nearly flat, drift-covered plains of the Central Lowland to the east. This escarpment, which is called the Missouri escarpment, is virtually continuous across the State of North Dakota southward into South Dakota. The base of the Missouri escarpment is the eastern boundary of the Great Plains in these northern states.

By far the largest number and area of basin wetlands in the PPR occurs in the Central Lowland. Most of this land mass drains either to Hudson's Bay (North Dakota) or the Gulf of Mexico (Iowa, Minnesota and South Dakota). Within the Central Lowland lie six major physiographic regions. These are, in decreasing order of area, the Glaciated Plains (921,000 km<sup>2</sup>), Prairie Coteau (15,200 km<sup>2</sup>), Dakota Lake Plain (5700 km<sup>2</sup>), Souris Lake Plain (3600 km<sup>2</sup>), Devil's Lake Plain (1400 km<sup>2</sup>), and Turtle Mountains (1200 km<sup>2</sup>). Reference wetlands from the Glaciated Plains, Missouri Coteau and the Prairie Coteau are included in this guidebook.

It is important to recognize the various physiographic divisions to adequately capture the diversity of the PPR. For purposes of this guidebook, the reference domain will be discussed in the context of the Glaciated Plains, Prairie Coteau and the Missouri Coteau major physiographic regions.

## Geology

Glaciation events during the Pleistocene Epoch were the dominant forces that shaped the landscape of the PPR (Winter 1989). About 7 million years ago, the subtropical climate of what is now the PPR began to change to a continental climate of cool winters and warm summers (Bluemle 1991). During the Pleistocene Epoch that followed, a succession of great ice sheets inched southward from Canada and covered most of Minnesota, the Dakotas, northern Montana and Iowa. These huge glaciers transported vast quantities of rock and soil. Large amounts of local silty and clayey bedrock outcrops were also pulverized and added to the mixture, forming glacial drift or "till" that was deposited as sediment across most of the area glaciated. The most recent episode of glaciation, the Late Wisconsin (approximately 20-25,000 years before present) is responsible for development of most of the present day landscape of the PPR. When the glaciers retreated a landscape dotted with numerous small, saucer-like depressions was exposed. These depressions, caused by the uneven deposition of glacial till, the scouring action of glaciers, and the melting of large, buried ice blocks are known today as prairie potholes.

The retreat of the glaciers marked the beginning of the Holocene Epoch about 10,000 years ago, as winters became cold and summers became hot (Bluemle 1991). The spruce-aspen forests of what are now the northern plains were succeeded by grasslands, and since that time, periods of warm, dry conditions have alternated with periods of cool, wet conditions (McAndrews, Stewart and Bright, 1967). Some additional basins were formed during this period from wind-worked sand dunes, but nearly all of the depressional wetlands in the PPR were formed as a direct result of glaciation or the melting of glacial ice. The area of depressional topography formed by a variety of geological processes comprises the PPR, which until the advent of European man, was an approximately 715,000-km<sup>2</sup> grassland-wetland complex that

stretched from north-central Iowa to central Alberta. The deposition of glacial till was unevenly distributed throughout the PPR. Large moraines accumulated along the terminal ends of glaciers and formed ridges of low, rolling hills in a northwest to southeast orientation, such as the Missouri Coteau and the Prairie Coteau. In these areas the glacial deposits are thick, and large-scale glacial stagnation processes predominated, resulting in a hilly, “knob-and-kettle” irregular surface with numerous wetlands and lakes (Figure 3).



Figure 3. Aerial oblique of the Missouri Coteau, North Dakota illustrating non-integrated surface drainage (source: U.S. Fish and Wildlife Service).

The landscape of the Coteau's formed because glaciers were forced to advance up a steep escarpment before they flowed onto the uplands. As glaciers advanced over the escarpment, sediment from the base of the glacier was forced up to the surface. When the climate moderated and the glaciers stagnated, sediment melting out of the ice accumulated at the surface, insulating the ice so that it took several thousand years to melt completely. As it melted, sediment slumped and slid forming the hummocky topography. Prairie potholes are most numerous where large-scale glacial stagnation processes dominated. This type of topography tends to have basins with steeper sides and more wetlands with semi-permanent water regimes.

Where glaciers retreated quickly, large, gently rolling areas of glaciated plains were formed, and extremely flat lake beds developed where glaciers dammed meltwater. The Glaciated Plains is a rolling, glaciated landscape also known as the drift prairie. Much of the region is very gently sloping, in some places, the ice shoved and thrust large masses of rock and sediment forming ice-thrust hills near the ice margin. In still other areas, loose accumulations of rock and sediment piled up at the edge of a glacier, resulting in areas of especially hilly land called end moraine. This landscape tends to have more numerous, but shallower, basins than the areas

where glacial stagnation processes occurred. Most wetlands on the Glaciated Plains have temporary or seasonal water regimes and are more susceptible to modification (Figure 4).



Figure 4. Aerial oblique of prairie pothole wetlands in an agricultural landscape matrix, Glaciated Plains, North Dakota (photo source: U.S. Fish and Wildlife Service).

Drainage patterns in these glaciated landscapes range from non-integrated patterns, where no streams flow through the areas (Missouri Coteau and Prairie Coteau), to land where poorly developed stream systems have developed (Glaciated Plains), to areas on the Des Moines Lobe where “linked depression systems” (Galatowitsch and van der Valk 1994) are the norm.

#### **Glacial Landforms Included in the Regional Subclass**

Within these physiographic divisions are a variety of glacial or postglacial landforms. Those landforms that contain relatively numerous wetland basins are as follows:

**Ground moraine:** This is the predominant glacial landform of the Glaciated Plains and can be recognized by a gently rolling landscape with numerous shallow saucer-shaped depressions, but few hills or deep cup-shaped depressions (Bluemle 1991). This landform occurs where moderate amounts of glacial till were deposited at the base of a moving glacier and by collapse from within the glacier when it finally melted. Most of the Glaciated Plains in eastern North and South Dakota, Minnesota and Iowa are ground moraine.

**Washboard moraine:** This form appears as small areas of irregularly spaced ridges of material thought to have been carried upward through the ice along shear planes parallel to the edge of the glacier (Bluemle 1991). Small basins are numerous in washboard moraine. This landform is mostly found in association with ground moraine in the Glaciated Plains.

Thrust moraine: This is perhaps the most spectacular glacial landform, as it is the result of large-scale glacial shearing that moved blocks of land up to 20 km in area for short distances (Bluemle 1991). The "hole" left by these blocks commonly resulted in a large lake, whereas the hilly blocks often contain numerous small but relatively deep basins. Devils Lake and Sulley's Hill in North Dakota are classic examples of thrust moraine topography. Most thrust moraine is found in the Glaciated Plains.

Terminal moraine: This form resulted when glacial till was deposited at the edge of a glacier while the ice margin was melting back at about the same rate as the ice was moving forward (Bluemle 1991). Till is a general term for the mixture of materials ranging in size from clay particles to boulders of many tons that were pushed forward by and carried on top of advancing glaciers. Terminal moraines are most common in the Glaciated Plains, but also occur in the Missouri and Prairie Coteaus. These moraines are commonly 2-15 km wide and 5-90 km long. Basins in terminal moraine are highly variable in size, depth, and density. The Bemis end moraine in Iowa is the southern boundary of the PPR (Harr et al. 1990).

Dead - ice moraine: This form is responsible for some of the most rugged glacial topography in the PPR, it formed when glaciers advanced over steep escarpments. Shearing action carried material into and on top of the glacier (Bluemle 1991). This insulated the underlying ice, which took several thousand years to melt and collapse. When the overlying materials slumped and slid, thousands of basins of all shapes and sizes were formed. Dead-ice moraine is the most common landform in the Missouri Coteau and the Prairie Coteau. Smaller amounts of dead-ice moraine occur in the Glaciated Plains.

Ice - walled and elevated lake plains: These features were formed when small lakes on areas of insulated glacial ice in the coteaus were flooded. As the ice melted, the sediment that had been deposited in the lakes slumped into irregular landforms. These small lake plains exist today as elevated lake plains standing above the surrounding land. These small, elevated lake plains are included in the reference domain, larger lake plains (e.g. Red River Valley, Lake Souris) are not included.

## **Parent Materials**

The PPR is an extensive Wisconsin-aged glacial terrain that has a mantle of fine-textured glacial till draped over sedimentary rocks of Mesozoic and Cenozoic age (Bluemle 1991). The tills in the PPR are finer textured than most tills throughout the U.S. This characteristic of glacial till in the prairie region has a significant impact on the surface and ground water hydrology of the region (Winter 1989). Typically, tills of the PPR contain substantial amounts of calcareous minerals that buffer the soil at slightly alkaline (Richardson, Arndt, and Freeland 1994.) Most of the tills are loams and clay loams; the term often used to describe the typical till is calcareous clay-loam till (Bluemle 1991). Thin lacustrine sediments are occasionally superimposed on the glacial terrain. The lacustrine sediments that are included in this guidebook are finer textured off-shore sediments that are silt loams to silty clays. The small depressional wetlands on these lacustrine areas commonly occur as elevated or "perched" lake plains (Bluemle 1991). Wetlands occurring in large areas of lacustrine materials such as the Red River Valley (Lake Agassiz), Dakota Lake Plain and Lake Souris are beyond the scope of this guidebook.

## Climate

The PPR is in the mid-continent of North America and is subject to the climatic extremes of this region (Winter 1989). Temperatures can exceed 40° C in summer and -40° C in winter. Isolated summer thunderstorms may bring several centimeters of rain in localized areas while leaving adjacent habitats entirely dry. Also, winds of 50 to 60 km hr can quickly dry wetlands during the summer.

Besides the normal seasonal climatic extremes, the semiarid western PPR also undergoes long periods of drought followed by long periods of abundant rainfall. These wet/dry cycles can persist for 10 to 20 years (Duvick and Blasing 1981; Karl and Koscielny 1982; Karl and Riebsame 1984; Diaz 1983, 1986). During periods of severe drought, most wetlands go dry during summer, and most of the temporary and many of the seasonal wetlands remain completely dry throughout the drought years. Exposure of mud flats upon dewatering is necessary for the germination of many emergent macrophytes, and it facilitates the oxidation of organic sediments and nutrient releases that maintain high productivity. When abundant precipitation returns, wetlands fill with water and much of the emergent vegetation is drowned. Changes in water permanence and hydroperiod by normal seasonal drawdown and long inter-annual wet/dry cycles has a profound influence on all PPR biota, but is most easily observed in the hydrophytic community (van der Valk and Davis 1978a).

The PPR has a north-to-south and a west-to-east precipitation gradient, with areas to the north and west receiving less precipitation than those to the south and east. However, even in the wetter southeastern portion of the region, wetlands have a negative water balance. Evaporation exceeds precipitation by about 60 cm in northeastern Montana and by 10 cm in Iowa (Winter 1989). Depression focused recharge occurs in the small prairie pothole wetlands because of this precipitation deficit.

The PPR has a climate characterized by relatively short, moderately hot summers and relatively long, cold winters because these states lie in the middle of a large continent at middle latitudes. Temperature and precipitation data for several locations in the PPR are summarized for a 30-year period (1961 - 1990) and are shown in Table 5.

<b>Table 5.</b> <b>Prairie Pothole Region Climatic Data.</b>				
Location	Temp. Avg. Daily Min. (Degrees C)	Temp. Avg. Daily Max.	Temp. Avg. Annual	Precipitation Avg. Annual
Medicine Lake, MT	-19 (Jan.)	30 (July)	5.7	33.7 cm
Brookings, SD	-18 (Jan.)	28 (July)	5.7	57.8 cm
St. James, MN	-15.5 (Jan.)	29.5 (July)	7.7	68.4 cm
Fort Dodge, IA	-14 (Jan.)	30 (July)	8.7	86.2 cm

Temperatures form roughly south-to-north gradients in the Prairie Pothole Region. Normal annual temperature ranges from about 4.4°C in northern North Dakota to about 9°C in central Iowa. Soils usually freeze to depths of 0.9-1.8 m in the northern PPR and 0.5-0.9 m in the southern PPR (adapted from Winter 1989).

Hare and Hay (1974) have attributed the relatively small amount of precipitation in the Canadian prairies to the weakness of atmospheric disturbances and their associated uplift. Air masses move eastward from the Rocky Mountains and fall steadily toward lower elevations in the northern prairies. The rate of fall is sufficient to reduce cyclonic action appreciably, thus reducing the effectiveness of the mechanism that causes precipitation. This phenomenon also reduces precipitation in the Prairie Pothole Region of the Dakotas and Montana. The southern part of the region has more precipitation because it receives more moisture-laden air masses from Gulf of Mexico.

Average annual precipitation in the region ranges from about 34 cm in northeastern Montana, 58 cm in eastern South Dakota to 86 cm in north central Iowa. Larger amounts of spring and summer precipitation in the southeastern part of the region account for most of this difference. About 70% of the annual precipitation falls as rain during spring and summer, with June the wettest month. Distinctly dry years, having <75% of normal precipitation, occur with 10% frequency in northwestern North Dakota, but only 4% in central Iowa. There is a large gradient across the Prairie Pothole Region in the length of the relatively dry season, that is, when weekly normals of <1.27 cm of precipitation can be expected. In northwestern North Dakota, this season averages 8-10 months, whereas in central Iowa, this season lasts only 2-5 months. Normal annual water loss by runoff and evaporation is 0.36 m in northwestern North Dakota and 0.56 m in southeastern South Dakota; the rest enters the ground.

## Cyclic Processes and the Reference Standard Cycle

Regional climate variability leads to both inter- and intra-annual fluctuations of seasonal mean temperature, humidity and precipitation. Average annual precipitation for Bismarck, ND is about 46 cm, 75% of which falls during the growing season of April through September. The principal water sources for prairie wetlands in this regional subclass are runoff from snowmelt, as well as precipitation, and the principal water loss is evapotranspiration (Shjeflo 1968). So, although the majority of the precipitation falls during the growing season, the rate of regional evapotranspiration leads to an overall draw down of the wetland water depths. It is important to note that a site can be a reference standard site as long as it is on the natural cycle. In other words, hydrologic conditions described above are within the range of the reference standard conditions since cyclic processes characterize the subclass. For instance, although the hydrologic conditions may be in a drawdown period and the associated characteristics (e.g. vegetation species composition) have responded accordingly, the overall functions of the wetland have not changed. This guidebook is written for these overall wetland functions.

## Hydrology

### Water Sources

Hydrologic regimes are dictated by climate and geology that establish the environment for hydrologic processes (Winter 1989). Atmospheric, surface, and ground water interact with basin topographic setting and the hydraulic characteristics of glacial tills to establish wetland hydrologic functions. The Northern Prairie of North America has a continental climate

characterized by cold winters, hot summers, and extreme variations in both temperature and precipitation (Winter 1989). Precipitation varies from semi-arid in the west to sub-humid in the east. Yearly variations in both temperature and precipitation extremes are common. Broad seasonal fluctuations in precipitation are nested within multi-year cycles, resulting in drought and pluvial wet cycles as the norm.

Yearly percent of snow cover is an expression of climate that directly influences wetland hydrology because snow cover and frozen ground act to delay groundwater recharge and strongly influence runoff / infiltration dynamics. In the northern PPR the ground is frozen and snow covers the surface between 30-50 percent of the time (Arndt and Richardson 1988). Temporary and seasonal wetlands of the Northern Prairie typically receive a large portion of their water volume as surface runoff during spring snowmelt (Hubbard and Linder 1986), when frozen ground minimizes infiltration (Malo 1975), and low temperatures and dormant plant communities minimize evapotranspiration losses (Shjeflo 1968; Lissey 1971; Sloan 1972). Shjeflo (1968) determined that snow accounts for at most 25 percent of total yearly precipitation, yet it accounts for at least 50 percent of the water that reaches the wetland. Overland flow from high-intensity thunderstorms (Lissey 1971) accounts for the major portion of the remaining hydrologic input.

Because surface runoff is the major hydrologic input to these wetlands, they need a relatively large catchment area as a water source. Arndt and Richardson (1988) determined that seasonal recharge wetlands have catchment area to wetland surface area ratios that range from approximately 6 to 10. The seasonal flow through wetlands in their study had ratios of less than 6, indicating a groundwater component of the water budget. In the northern PPR, wetlands that are usually dry by midsummer recharge shallow groundwater aquifers (Richardson, Arndt, and Eilers 1991). This is the long-term dominant process; however, it is important to note that flow reversals can occur both seasonally and yearly depending upon climatic cycles, presence of phreatophytes, and proximity to more permanent wetlands.

Another important measure of climate that directly relates to wetlands and integrates the effects of temperature and precipitation is the difference between precipitation and evapotranspiration. The northern PPR is characterized by a moisture deficit, whereas the eastern glaciated regions have moisture excess. In the northern PPR, potential yearly evapotranspiration generally exceeds mean yearly precipitation (Winter 1989). This sub-humid to semi-arid climate results in surface / groundwater interactions that are depression focused (Lissey 1971). The alternate drought and wet (pluvial) periods produce decade-long cycles of water table fluctuations. The temporary and seasonal wetlands that are the focus of this Guidebook commonly go through draw-down stages where surface ponding is rare or absent for several years.

Many seasonal wetlands (especially those in the eastern part of the PPR) have a component of groundwater discharge as part of their hydrologic budget. These areas can be characterized by the presence of slightly saline tolerant plant communities, calcareous soils and smaller size catchments. The correlation of plant communities, soil morphology, hydroperiod and hydrologic function is well documented in the literature (Arndt and Richardson 1988; Bigler 1981; Fulton, Richardson, and Barker 1986; Hubbard, Beck, and Schultz 1987; Miller, Acton, and Arnaud 1985; Sloan 1970).

The principal hydrologic function of these wetlands is that of surface water storage because of their location as the lowest point in closed watersheds. Groundwater recharge is a secondary hydrologic function for many wetlands of this subclass because the dominant source of water is relatively fresh water from surface runoff and direct precipitation, the climatic setting

resulting in depression focused groundwater interactions, and the fine textured substrates. The cumulative total of these small wetlands has a tremendous effect on the overall groundwater flow net of the PPR.

### Hydrodynamics: Water Movement

Temporary and seasonal potholes exhibit extreme vertical fluctuations of water levels. In pluvial cycles they commonly fill above the wetland boundary and can overflow onto adjacent landscapes and down slope to other depressions (Leibowitz and Vining 2003). As illustrated in Figure 5, these wetlands exhibit both long- and short-term fluctuations in ponding depth. The absence or presence (and elevation of) outlets is important and may result in some functions during wet cycles that are more commonly associated with wetlands on open landscapes.

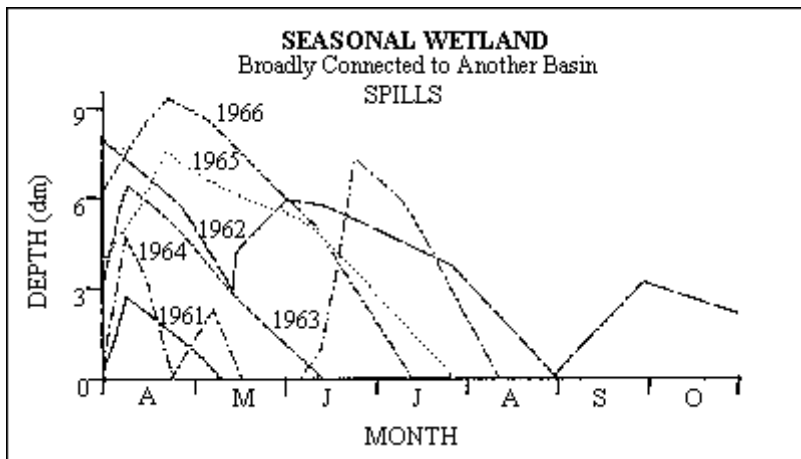


Figure 5. Water level changes during the ice-free season over a 6-year period in a seasonal basin wetland in North Dakota (adapted from Kantrud, Krapu, and Swanson 1989).

The PPR landscape is characterized by a mosaic of ponds varying in depth at a single point in time, thus contributing to diverse habitats. This is a result of the elevation or lack of surface outlets to these wetlands. Floodwaters can be detained permanently or attenuated by these small depressions (Hubbard and Linder 1986). The hydrodynamics contribute to groundwater recharge, maintenance of salt balance in the landscape, maintenance of anaerobic conditions, and fluctuations between anaerobic and aerobic conditions. The retention of surface waters in these depressions results in an aquatic / moist habitat in an otherwise sub-humid to semi-arid landscape. These conditions are directly related to biogeochemical functions.

### Soils

Most soils of the reference system have formed in calcareous loamy glacial till. The wetland basins have soils formed in glacial till which often have a surface of post-Pleistocene local alluvium / colluvium (slopewash) from the surrounding uplands. This subclass also includes small depressional wetlands formed in clayey till and clayey lacustrine sediments. Most temporary and seasonal wetlands in the PPR are ponded with fresh water and have leached soil profiles consistent with their hydrologic function (Richardson, Arndt, and Freeland 1994). Temporary wetlands in the PPR are characterized by wet-meadow (Stewart and Kantrud 1971) or sedge-meadow (Galatowitsch and van der Valk 1994) vegetation. The soils in Temporary wetlands vary throughout the region with Argialbolls (e.g Tonka, Tetonka series) dominating in

Montana, North Dakota and South Dakota (i.e. northern PPR) and Endoaquolls dominating in Minnesota and Iowa. Seasonal wetlands are characterized by shallow-marsh vegetation in the basin center surrounded by a wet-meadow zone. The soils in seasonal wetlands of the northern PPR are commonly Argiaquolls (e.g. Parnell, Worthing series) or non-calcareous, fine-textured Cumulic Endoaquolls in the center. These soils grade to Argialbolls and fine-loamy Endoaquolls in the wet meadow zone and often have a rim of Calciaquolls (e.g. Vallers)

Some seasonal wetlands have a component of groundwater discharge as part of their hydrologic budget. These areas can be identified by the presence of slightly saline tolerant plant communities, calcareous soils and slightly lower catchment area / wetland surface area ratios (Arndt and Richardson 1988).

Freeland and Richardson (1996) evaluated prairie wetland soil properties as indicators of sedimentation as it impacts wetland condition. They propose that soil Phosphorous (Olsen et al. 1954) in the 0 to 15 cm depth is the best indicator of wetland condition. They also recommend that organic matter content and soil texture analysis is included in future wetland condition studies. Galatowitsch and van der Valk (1996) sampled restored (< 5 years since re-flooding) and natural prairie wetlands in north-central Iowa. They found that the restorations had only 1/3 to 2/3 as much organic carbon as the natural wetlands. Another project found that soils in native (i.e. reference standard) prairie pothole wetlands had as much as 1.5% (i.e. 1/3) more organic carbon than restored wetlands with a cultivated history (Olness, Euliss, and Gleason 2002).

## Vegetation

Major themes of the phytosociological literature for the PPR consist of: zonation patterns, wetland classification, vegetation dynamics, environmental/plant relationships and impacts of anthropogenic disturbance. All of the preceding themes are interrelated and must be viewed in concert. The reader is referred to Stewart and Kantrud (1972); Kantrud, Krapu, and Swanson (1989); Kantrud, Millar, and van der Valk (1989); and van der Valk (2000) for in depth syntheses of the prairie pothole plant ecological literature.

Specifically, factors influencing species composition and distribution along the gradient (zonation) in Prairie Pothole wetlands include hydrologic regime, salinity of water, edaphic complex, plant competition, pH, nutrient status and the seed banks (Dix and Smeins 1967; Walker and Coupland 1968; Walker and Wehrhahn (1971); Dirshl and Coupland 1972; Stewart and Kantrud 1972; Millar 1973; and van der Valk and Davis 1978a). Zonation in prairie depressional systems is a function of the water depth and duration (van der Valk 1981). Characteristic life forms and species assemblages dominate each vegetative zone. Life forms are commonly accepted as indicators of hydroperiod (Kantrud, Millar, and van der Valk 1989). The complexity of zonation typically increases with the length of time a wetland holds water during the growing season, and species richness generally decreases with increasing water permanence (Kantrud, Krapu, and Swanson 1989).

Observations on vegetation zonation and plant /environmental relationships have formed the basis of wetland classification for the Prairie Pothole Region. Stewart and Kantrud (1971) developed a classification specifically for the glaciated prairie region that was designed to classify entire basins. Classes of interest for this Guidebook are Class II, temporary ponds; and, Class III, seasonal ponds and lakes. Next in this classification scheme are sub-classes defined by water chemistry, ranging from fresh to moderately brackish. Following the sub-class designation, basins are further described by the central zone. Vegetation zones applicable to this Guidebook,

in order of increasing degree of water permanency, are the low prairie, wet meadow, and shallow marsh (see Figure 6).

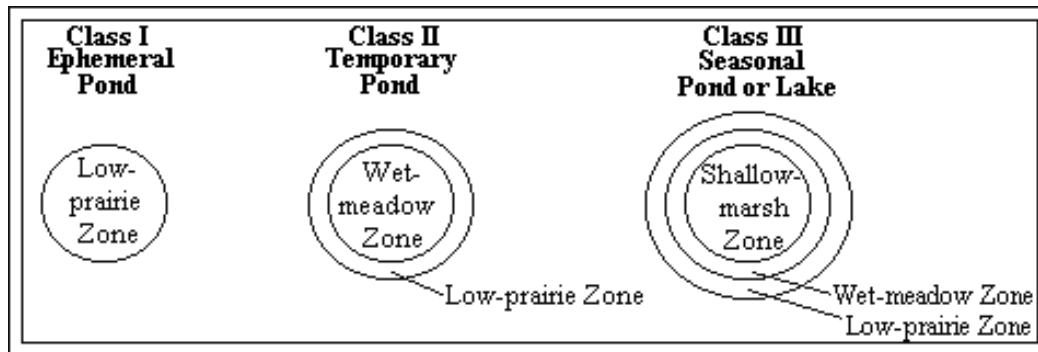


Figure 6. Generalized Stewart and Kantrud (1971) wetland classes and vegetation zones discussed in this Guidebook.

Within zones, “phases” were assigned to describe variation from a “normal emergent” condition to species assemblages attributable to wet phases, drawdown conditions, water chemistry, or effects of cultivation. Floristic composition of these phases, in terms of primary and secondary species, are provided as an additional characterization. Ephemeral Ponds, Class I, are also contained in the Stewart and Kantrud (1971) classification but are not considered “jurisdictional” wetlands according to federal wetland delineation protocol (Environmental Laboratory, 1987) nor considered wetlands under the Cowardin et al. (1979) classification. They are, however, of interest for wetland functional assessment in terms of relating the site to its surrounding ecosystem. Table 6 provides a synopsis of the Stewart and Kantrud (1971) terminology used in this Guidebook and representative plant associations. Ephemeral ponds are included for illustrative purposes. More extensive list of plant species within the PPR region can be found in Stewart and Kantrud (1972).

<b>Table 6.</b> <b>Stewart and Kantrud (1971) classification corresponding to the prairie pothole HGM depressional subclass described in this Regional Guidebook.</b>	
<b>Class and subclass (water chemistry)</b>	<b>Central zone and representative species</b>
Class I - ephemeral ponds	Low -prairie vegetation
Fresh	<i>Poa pratensis, Solidago altissima</i>
Class II - temporary ponds	Wet - meadow vegetation
Fresh	<i>Poa palustris, Boltonia latisquama</i>
Slightly Brackish	<i>Hordeum jubatum, Calamagrostis inexpansa</i>
Class III - seasonal ponds and lakes	Shallow - marsh vegetation
Fresh	<i>Carex atherodes, Glyceria grandis.</i>
Slightly Brackish	<i>Scolochloa festucacea, Eleocharis palustris</i>
Moderately Brackish	<i>Alisma gramineum, Beckmannia syzigachne</i>

Both allogenic and autogenic forces operate to change wetland vegetation. Vegetation responds to wet-dry cycles on both an intra- and inter-annual basis. van der Valk and Davis (1978a) described the vegetation dynamics for prairie depressional systems. The presence and abundance of each species depends on its life history strategies and its adaptation to the site. Propagule dispersal type, seed bank characteristics, competition, mortality, and various

combination of these and other environmental factors are responsible for observed plant distribution along the moisture gradient (van der Valk 1981). Zonation patterns are, therefore, a collective result of hydro- dynamics and individual species' ability to respond to changing environmental conditions.

Species assemblages also vary with the type and/or intensity of disturbance. Prior to European settlement, plant communities in the PPR evolved in response to fire and grazing by native ungulates. Fire suppression and changes in grazers to domesticated species has altered plant /environmental relations where the "natural disturbance regime" has been changed to an anthropogenic disturbance regime. Little is known about the environmental effects of fire in prairie wetlands (Kantrud 1986). Much of the available information is from inferences on fires set in a variety of vegetation types and some general observations on emergent vegetation response. Fire has been used as a management tool to increase cover interspersion by opening up dense emergent stands, to control exotic species in combination with other treatments, or to select for food sources in waterfowl management practices.

Much more is known about the effects of grazing than of burning on wetland plant communities. Low to moderate grazing intensity results in greater plant species diversity and the development of more intricate patterns and sharper boundaries among plant communities (Bakker and Ruyter 1981; Kantrud 1986). Overgrazing can decrease productivity, increase water turbidity, or reduce cover and habitat structural components for fauna requiring wetlands for some or all of their life cycle requirements.

Artificial drainage and cultivation of wetlands habitat has altered species composition and selected for annual and /or invasive species. Drainage features inhibit characteristic hydro-dynamics, which in turn selects for species with opportunistic life cycle requirements. Cultivation was considered the most drastic type of disturbance by Walker and Coupland (1968) and considered to "override" the effects of other natural gradients. Dix and Smeins (1967) also addressed cultivation and observed an irregularity in stand ordinations for cultivated depressions. As inferred from a comparison of vegetation in less disturbed sites, these authors noted that vegetation composition for cultivated areas was "wetter" on the moisture gradient than would be anticipated.

In their evaluation of vegetation-based indicators for wetland assessment, Kantrud and Newton (1996) stated that basins in "poor-quality" watersheds tended to have fewer communities (zones). Wetland basins within a cultivated catchment also have greater fluctuation in water levels as compared to those having grassland catchments (Euliss and Mushet 1996). Transport of sediments from the tilled upland to the basin is accelerated during runoff events (Martin and Hartman, 1987). The covering of seed banks with sediments inhibits re-colonization. Disturbance to a wetland by repeated cultivation probably affects all stages in the plant regeneration cycle, an important mechanism in the maintenance of plant species diversity (Grubb, 1977). Gleason et. al (2003) evaluated the effects of sediment burial on emergence of plants and invertebrates from seed and egg banks. For vegetation aspects of their study, sediment load experiments indicated that burial depths of only 0.5 cm caused a 91.7% reduction in seedling emergence.

## Fauna

The faunal component of Northern Prairie depressional systems has been extensively studied for both vertebrate and invertebrate taxa. Major syntheses of the literature can be found

in Hubbard (1988); Kantrud, Millar, and van der Valk (1989); Swanson and Duebbert (1989); Murkin (1989); Batt et al. (1989); and Fritzell (1989). Wet-dry cycles, vegetation composition, water chemistry, and anthropogenic disturbance have all been described as major factors controlling faunal composition. The PPR is a major breeding area for waterfowl (Weller 1987) and therefore, most literature is focused on relationships of waterfowl to habitat in terms of pair use of different wetland classes, feeding ecology, and nutritional requirements for fulfilling life-cycle requirements.

Important roles of invertebrates in ecosystem processes have been summarized by Euliss, Mushet, and Wrubleski (1999). These roles include trophic linkage from primary production to secondary consumers, providing specific nutritional components such as amino acids and micronutrients for vertebrates, and detrital processing of wetland organic material. This HGM subclass provides isolation for breeding pairs and supplies invertebrate foods for waterfowl early in the nesting period. Small shallow wetlands in the PPR are the first to “ice-out” in the spring. Rapid warming of these shallow wetlands results in early development of invertebrate populations (Swanson, Meyer, and Serie 1974) and provides a major source of protein for consumption by laying female ducks (Kantrud, Krapu, and Swanson 1989).

Adamus (1996) stated there is limited information on amphibian communities for prairie wetlands, but available information suggests sensitivity to some contaminants and lowered population viability due to habitat fragmentation. Lehtinen, Galatowitsch, and Tester (1999) examined the significance of habitat loss and fragmentation affecting amphibian assemblages in glacial marshes. Results indicated that decreases in landscape connectivity via fragmentation and habitat loss affect amphibian assemblages. Amphibian species richness was lower with greater wetland isolation and road density.

The PPR ecosystem supports more than 200 species of migratory birds and produces more than 50 percent of the ducks inhabiting North America, even though it accounts for only 10 percent of the entire North American duck breeding area. Kantrud, Millar, and van der Valk (1989) discussed the importance of pothole wetlands with observations from North Dakota. Approximately 39% of the 353 valid species on the North Dakota bird list (Faanes and Stewart 1982) use wetlands. Of the 223 species with known or inferred breeding status in North Dakota, 26% are marsh or aquatic birds other than waterfowl. Information on use of prairie wetlands by migrants and summer visitors is limited, but the regional landscape provides habitat for millions of arctic/ subarctic-nesting shorebirds and neo-tropical migrants that pass through the Prairie Pothole Region each spring and fall.

Avian species habitat preference, response to hydrodynamics, and vegetation manipulation have been summarized by Weller and Spatcher (1965), Swanson and Duebbert (1989), Batt et al. (1989); and, Kantrud (1986). These studies state that decreased wetland use by water birds is a result of anthropogenic disruption to natural ecological processes in the upland catchment or within the wetland. In the absence of natural processes, succession trends toward establishment of monotypic hydrophytic stands, thereby decreasing habitat suitability. Adamus (1996) also stated factors affecting faunal use are principally disturbance oriented and can be interpreted through vegetation structure or other physical features of the surrounding habitat.

Use of prairie wetlands by mammals has been described Fritzell (1989). Species were categorized based on the degree of dependence on wetlands for cover or to obtain a substantial portion of their food. The majority of mammals discussed regularly make extensive use of prairie wetlands or complete their life-cycle in moist transition areas. Wetland habitats are of direct importance to many species and some mammals markedly affect other components of wetland

ecosystems. Muskrats (*Ondatra zibethicus*) are major elements of prairie wetland ecosystems in terms of altering vegetation composition, habitat structure, and nutrient exchange. Mink are closely associated with basin wetlands and can cause significant mortality of marsh birds (Katrud, Krapu, and Swanson 1989).

When evaluating habitat functions, an individual assessment site must be analyzed in the context of the surrounding wetland complex. Heterogeneity of wetland types within a complex creates habitat diversity inducing high species richness (Weller 1978). Talent, Krapu, and Jarvis (1982) found that as many as 10 different basins in close proximity were utilized by mallard broods. Hubbard (1988) discussed the shift in use by waterfowl broods from seasonally-flooded basins to semi-permanently-flooded basins within a complex based on decreasing water availability on an intra-annual basis. Cowardin, Shaffer, and Arnold (1995) evaluated dabbling duck production and recruitment based on inter-annual precipitation cycles. Pond density (basins holding water) decreased within the period of study (1987-1990) due to drought. Density of breeding pairs per pond was inversely related to pond density, suggesting that breeding ducks tended to concentrate on the remaining ponds as drought intensified. Recruit production followed a similar pattern to breeding size populations.

On both temporal and spatial scales, close proximity of wetland basins of different hydroperiods is critical to resource availability and subsequent exploitation by waterfowl. According to Johnson, Haseltine, and Cowardin (1994), understanding these two characteristics of the region, spatial heterogeneity and temporal instability, is essential to sound habitat management. Habitat suitability for some species is related to local vegetation conditions within wetlands, while suitability for others is related to landscape structure at larger scales. Gibbs (1993), through simulation modeling, examined how loss of small wetlands altered the wetland mosaic and thereby affect meta-populations of wetland associated organisms. Results suggest that small wetlands play a greater role in meta-population dynamics of certain wetland dependent taxa than the “modest” area comprised by small wetlands may imply. At larger spatial scales, an unfragmented prairie-wetland mosaic provides habitat for more species than wetlands isolated in an agricultural landscape (Naugle et al. 2003).

## Anthropogenic Impacts

PPR wetlands are among the most productive ecosystems in the world. The characteristic drying and re-wetting cycles result in tremendous turnovers in primary productivity and elemental cycling. The high productivity and levels of detritus result in biodiversity comparable to other ecosystems such as rain forests. The extreme productivity of these wetlands also makes them the target of land use conversion. Many of the potholes were drained to create new lands for agriculture and to increase the efficiency of tillage operations. Wetland functions are lost when human activities physically convert wetlands to upland or deepwater habitats. Often, however, the conversion is not complete, and areas which continue to exist as wetlands have diminished functions.

Despite a lack of precise data on wetland losses in the PPR, the available information indicates losses have been significant. There is widespread agreement that the dominant land use in the region--agriculture--has been the primary cause of continuing wetland decline. Dahl (1990) estimated wetland area losses (%) from the 1780's to 1980's in the five-state PPR. Reported wetlands losses since the 1780's, by state, are provided in Table 7.

<b>Table 7.</b> <b>Estimated wetland losses for states within the Prairie Pothole Region.</b>		
State	% Loss	Remaining wetland area (ha.)
Iowa	-89%	170,870
Minnesota	-42%	3,523,500
Montana	-27%	340,322
North Dakota	-49%	1,008,450
South Dakota	-35%	720,900

## 4 Wetland Functions and Assessment Models

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### OVERVIEW

The following functions performed by PPR wetlands were selected for model development.

- A. Water Storage
- B. Groundwater Recharge
- C. Particulate Retention (Physical processes)
- D. Remove, Convert, and Sequester Dissolved Substances (Biochemical processes)
- E. Plant Community Resilience and Carbon Cycling
- F. Provide Faunal Habitat

### Reference Data

A total 180 reference sites were evaluated. Two data sets were used in this analyses, one data set collected by the inter-agency personnel (n= 65) and the other data set collected by the U.S. Geological Survey, Northern Prairie Science Center (n= 115) as part of their evaluation of wetland restoration activities throughout the PPR. A detailed description of their study approach and metrics is described in Euliss and Gleason, (1997). Data were collected from 1995 through 1999. The model variables selected for describing PPR functions were derived from these data sets.

The reference sites encompass a range of variation from cultivated to relatively undisturbed sites. The treatment groups may be referred to in discussion of some variables. Each site was described as belonging to one of the following treatment groups:

1. Restored wetlands < 5 years old (n=19): Wetlands in the Conservation Reserve Program (CRP) habitats or similar grasslands restored for 1-5 years. CRP type habitats are defined as once farmed lands that have been planted back to grassland cover. Hence, study sites may or may not be enrolled in CRP contracts.
2. Restored wetlands >5 years old (n=33): Wetlands in CRP or similar grasslands restored for >5-10 years.
3. Drained wetland analogue (n=35): Drained wetland analogues are drained wetlands in CRP habitats or similar grasslands and will be similar to restored wetlands with respect to land-use history, wetland area, catchment area, and soils.

4. Non-drained wetland analogue (n=33): Non-drained wetland analogues are non-drained wetlands (i.e., natural wetland) in CRP habitats or similar grasslands and are similar to restored wetlands with respect to land-use history, wetland area, catchment area, and soils.
5. Reference wetlands (n=38): These wetlands, for purposes of describing this treatment group, are defined as non-drained wetlands (i.e., natural wetland) in non-tilled (i.e., never tilled) grasslands. This may include hayland and native prairie habitats. Hence, land-use history of these wetlands will differ from the other categories, but will be similar with respect to wetland area, catchment area, and soils. This category was the least disturbed anthropogenically and served as candidates for potential reference standard sites.
6. Cultivated wetlands (n=22): Cultivated wetlands are defined as wetlands having a cropping history of > 5yrs.

The sampled reference domain includes portions of Montana, North Dakota, South Dakota, Minnesota, and Iowa. Reference sites were also stratified by the Missouri Coteau, Prairie Coteau, and Glaciated Plains physiographic regions. Locations and physiographic group designations for the reference sites are provided in Appendix C-1.

The HGM variables are scale dependent; incorporating zonal, site, catchment, and landscape metrics. Thematic data collected is described below and also summarized in Table 8.

<b>Table 8.</b> <b>List of information collected at reference sites by scale and themes</b> (Adapted from Euliss and Gleason, 1997).	
<b>WETLAND BASIN</b>	UTM coordinates Relative elevations Cropping history Area Shoreline length
<b>SOILS</b>	Soil classification % organic and inorganic Particle size Soil EC
<b>HYDROLOGY</b>	Water depths Maximum water depth Natural outlets and inlets Type of drainage Age of restoration Number of years ponded (since restoration) Length of time drained Completeness of drainage Elevation drainage plug Maximum elevation for enhancement
<b>VEGETATION</b>	Wetland class Number and extent of vegetation zones Percent open water Floristic composition / cover estimates
<b>CATCHMENT BASIN</b>	Cropping history Current land use Area Slope/elevation Generalized vegetation composition
<b>LANDSCAPE / WETLAND COMPLEX</b>	Inter-wetland distance Wetland area Number of wetland basins Linear distance of roads and drainage features

For site characterization at each reference site, transects were established so as to intersect the observed vegetation zones. Transect endpoints extended through the hydric soil boundary to surrounding uplands. At selected sites, a secondary transect line was established perpendicular to the main axis when needed. Soils and vegetation data were collected at intervals along the main and secondary transect lines. Vegetation sample locations along the transect were selected so as to characterize species' composition and abundance within each zone. A modified Daubenmire (1959) canopy coverage scale was used. Soil profile descriptions and lab samples were collected at vegetation sampling locations, additional soil profiles were evaluated at the discretion of the project's soil scientist. Basin topographic data and documentation of sites' features were collected using a theodolite. Attributes collected consisted of elevation and location of hydric soils, plant community boundaries, ditches, drainage tile intakes, culverts, transect endpoints, natural outlet, wetland depths and locations of vegetation/soils samples.

For catchment characterization, boundaries and area were determined from field surveys, aerial imagery and topographic maps. Catchment land use / land cover were documented in the field or from aerial photography. The spatial relationship of the vegetation zones, wetland and catchment is provided in Figure 7.

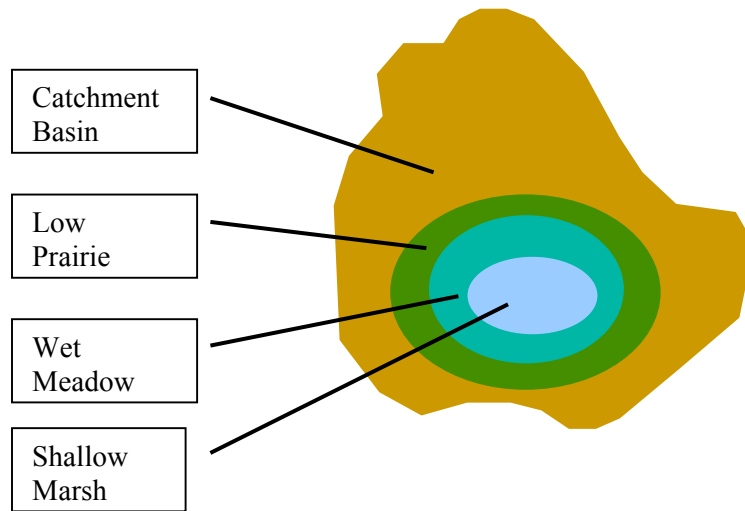


Figure 7. Generalized plan view of vegetation zones in relation to the catchment.

For Landscape Characterization, Geographic Information System (GIS) technology was utilized in landscape scale analyses. ARC-INFO software (ERSI, Redlands, California) was used in all data processing and analysis of digital data. Digital mapping data pertinent to this study included that of the National Wetland Inventory (Wilén, Carter, and Fretwell ;1996) and U.S. Census Bureau 1:100,000 scale data. National Wetland Inventory (NWI) digital polygon data were re-coded into single basin classes as described by Cowardin, Shaffer, and Arnold (1995). Selected linear features from the preceding sources were also used in reference site landscape characterization.

A Landscape Assessment Area (LAA) was circumscribed from a 1.6-kilometer radius from the center of the assessment wetland. The LAA area evaluated was 8.1 km<sup>2</sup>. This convention was artificially defined and is considered the surrogate for assessing the wetland complex. Inter-wetland distance of a reference site to the nearest five wetlands was measured, as well as the number of basins and area of wetlands within the complex. NWI linear wetland data with an “x” modifier (excavated) or “d” modifier (partly drained) and, all classes of roads derived from the U.S. Bureau of Census data were also summarized for the LAA.

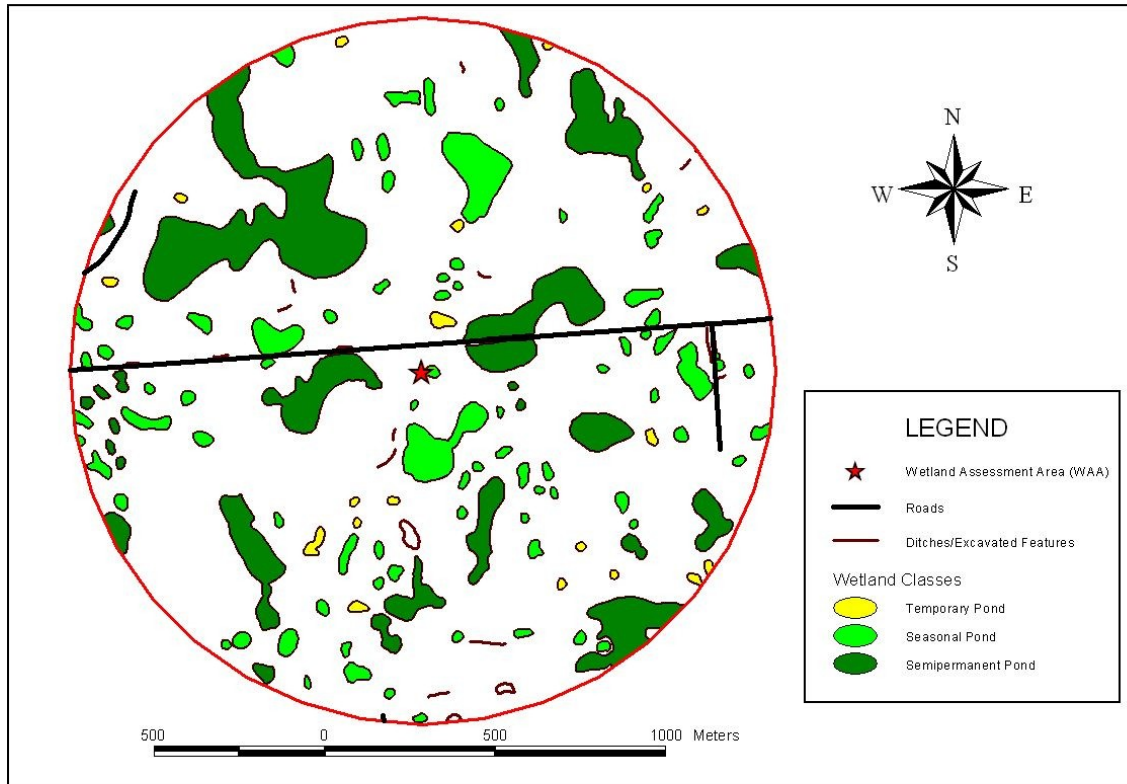


Figure 8. Landscape Assessment Area associated with a reference site in Stutsman County, North Dakota.

## Model Variables

The following variables integrate the results of reference data collection and are used to calculate the functional capacity indices:

### Vegetation

$V_{\text{GRASSCONT}}$  – Continuity of grassland adjacent to the wetland

$V_{\text{GRASSWIDTH}}$  - Width of grassland perpendicular to the wetland

$V_{\text{VEGCOMP}}$  -Vegetation Composition

### Soils

$V_{\text{RECHARGE}}$  - Estimated soil recharge potential

$V_{\text{SED}}$  - Sediment deposition in the wetland

$V_{\text{SQI}}$  - Soil Quality Index

$V_{\text{SOM}}$  - Soil organic matter

### Hydrogeomorphic

$V_{\text{OUT}}$  - Wetland surface outlet

$V_{\text{SUBOUT}}$  - Subsurface drainage

$V_{\text{SOURCE}}$  - Reduction or increase in catchment area

$V_{\text{EDGE}}$  - Modified shoreline irregularity index

$V_{\text{CATCHWET}}$  - Ratio of catchment area to wetland area

### Land Use and Landscape

$V_{\text{UPUSE}}$  - Land use within the catchment

$V_{\text{WETPROX}}$  - Proximity to nearest wetlands

$V_{\text{WETAREA}}$  - Wetland density in the Landscape Assessment Area

$V_{\text{BASINS}}$  - Number of Basins in the Landscape Assessment Area

$V_{\text{HABFRAG}}$  - Sum of the length of roads and ditches in the Landscape Assessment Area

In the next section, each variable is discussed in terms of the metrics, measurements and the relationship of the metric to the variable subindex score. After presentation of this information, assessment models for each of the functions are provided.

### Vegetation Variables

Grassland Continuity ( $V_{\text{GRASSCONT}}$ ):

This variable represents the average continuity of grassland around the perimeter of the wetland. Grassland continuity is measured by determining the perimeter (meters) of the wetland boundary that is contiguous with grassland. This measure is then divided by the total perimeter of the assessment wetland and is expressed as a percent for calculation of the variable subindex score. Percent continuity scores for the reference sites ranged from 0-100%. Based on the range of values at reference sites, a subindex of 0 indicates that no grassland was contiguous with the wetland edge and a subindex of 1.0 indicates the entire wetland

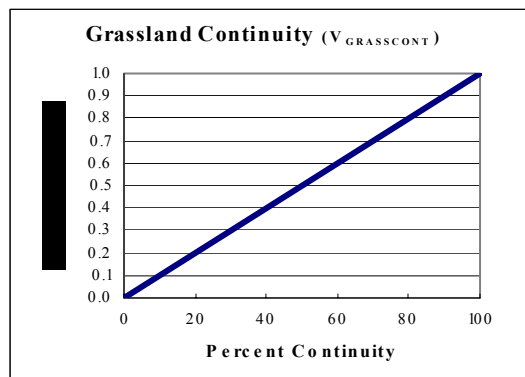


Figure 9. Relationship between the continuity of grassland adjacent to the wetland and the variable subindex.

perimeter was surrounded by grassland. The relationship of the metric to the sub-index score is presented in Figure 9.

#### Grassland Width ( $V_{\text{GRASSWIDTH}}$ )

This variable represents the average width in meters of grassland adjacent to the wetland edge. Grassland width is measured perpendicular from the wetland perimeter to a length 15 meters distant. The width of grassland is measured at a minimum of 12 equidistant intervals of the perimeter and the average width determined. A score of 0 indicates that there is no grassland surrounding the wetland. A variable subindex score of 1.0 is assigned when the average grassland width is  $\geq 15$  meters. For  $n = 180$ , mean value was 12 meters with a range from 0-15 meters. The relationship of the metric to the sub-index score is presented in Figure 10.

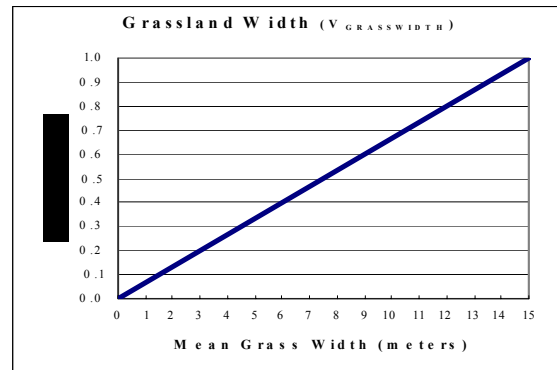


Figure 10. Relationship between the grassland width perpendicular to the assessment wetland and the variable subindex

#### Vegetation Composition ( $V_{\text{VEGCOMP}}$ )

This variable represents the floristic quality of a wetland as determined from a field survey of species' present within the wetland. The vegetation within a wetland is assumed to indicate overall native species richness and diversity. Calculation of this variable has been modified from the Floristic Quality Assessment Index procedures as described by Wilhelm and Ladd (1988). This vegetation based index has also been utilized by Swink and Wilhelm (1994), Andreas and Lichvar (1995), Herman et al.(1997) and Fennessy et al. (1998) to assess ecological integrity and to assist in natural areas analyses.

The process for development of this index is dependent upon assigning indicators to the regional flora of interest. Each species is assigned an indicator value based upon procedures in Taft et al. (1997). This involves assignment of a Coefficient of Conservatism (termed "C" value) to species records. Individual species indicators may range from 0-10 with "0" being considered invasive species and "10" being considered the highest fidelity to natural areas. General categories for species assignments consist of the following:

- X 0-1: Taxa that are adapted to severe disturbance, particularly anthropogenic. Disturbance occurs so frequently that often only brief periods are available for growth and reproduction. Generally considered ruderal species/opportunistic invaders.
- X 2-3: Taxa within this category are associated with more stable, though degraded habitat. Generally considered ruderal-competitive species, found in a variety of habitats.
- X 4-6: Taxa that have a high consistency of occurrence within a given community type and will include many dominant or matrix species for several habitats. Species will persist under moderate disturbance.

- X 7-8: Taxa associated mostly with natural areas but can persist where the habitat has been somewhat degraded. Increases in the intensity or frequency of disturbance may result in reduction in population size, or; taxa may be subject to local extirpation.
- X 9-10: Taxa exhibiting a high degree of fidelity to a narrow range of synecological parameters. Species within this category are restricted to relatively intact natural areas.

Source data for assignment of “C” values were from Northern Great Plains Floristic Quality Assessment Panel (2001), with modification. Modifications in assignments relate to woody and non-native species. Native woody species were considered “invasive species” for this herbaceous, depressional subclass. Also, for those plant records having a ‘ \* ‘ assignment, meaning non-native taxa, a “0” was assigned. Species records associated with reference data and “C” value assignments can be found in Appendix C-2. Botanical nomenclature follows conventions of the Northern Great Plains Floristic Quality Assessment Panel (2001).

The Floristic Quality Index is a species richness estimate that uses a square root transformation of N to limit the influence of area alone on species richness (Taft et al. 1997). Calculation of the Floristic Quality Index (FQI) is as follows:

1. Determine the mean coefficient of conservatism ( $\bar{C}$ ) by summarizing all coefficients in the inventory unit (reference site or WAA), and, divide by the number of taxa (N), or  $\bar{C} = \sum C/N$ .
2. Multiply the mean coefficient of conservatism ( $\bar{C}$ ) by the square root of the total number of taxa (N).

The Floristic Quality Index is represented mathematically as:

$$FQI = \bar{C} * (\sqrt{N})$$

Analyses of reference data indicated a positive correlation of FQI with native species richness and native species abundance. For  $n=180$ , the Spearman Rank Correlation Coefficient, indicated  $r = .908$   $p > .01$  for FQI versus native species richness; and, for FQI versus native species abundance,  $r = .373$ ,  $p > .01$ . Mean value of FQI scores was 10.30. Index values ranged from .33 to 30.04. The reference standard condition for this variable was set at values  $\geq 16.00$ . Due to the variability of above and below ground biomass on an intra- and inter-annual basis, FQI is used as a surrogate for live biomass. Correlations of floristic quality indices with biomass have been reported by Fennessey et. al. (1998b) in Ohio wetlands and by Lawrence (personal communication) for Rainwater Basin depressional wetlands. The relationship of the metric to the sub-index score is presented in Figure 11.

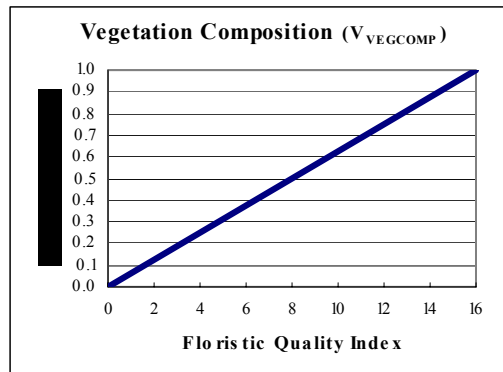


Figure 11. Relationship between the Floristic Quality Index and the variable subindex.

The Floristic Quality Index, using species surveys, is the preferred method for characterization of vegetation composition. Alternate measures for this variable are also based upon plant indicator rankings and are described in Appendix C-3. Measures include a dominance option based on percent concurrence with reference standard dominant species and a weighted average option for use where plant abundance is needed in analyses. Use of these alternate methods is based upon the level of detail required for user defined assessment objectives.

## Soil Variables

Soil is a major structural component of wetland ecosystems, and it has several important functions within these ecosystems. Soil is a medium for plant growth, soil biological, chemical, and physical properties influence the structure and function of plant communities. Second, soil properties control the fate of water in the hydrologic cycle. The soil acts as a system for water supply and purification. Third, soil provides habitat for living organisms. Many of these organisms feed on waste products and body parts of other organisms, releasing their constituent elements back into the soil for uptake by plants. The soil thus acts as a recycling system for nutrients and organic wastes (Montgomery, Tandarich, and Whited 2001). The soil variables used in this guidebook focus on soil properties to estimate the degree of sedimentation, to physically allow movement and storage of water, biogeochemical cycling, plant habitat, and the building block of wetland food webs. Four variables are presented. For one variable,  $V_{SOM}$ , direct and indirect metrics are provided.

### Soil Recharge Potential ( $V_{RECHARGE}$ )

This variable is an indirect measure of potential recharge based on the areal extent of soil types (soil series or Great Group) in the wetland. It is determined on-site by making a site-specific soil map and obtaining the extent of different soil types. The soil types are then used in conjunction with Appendix C-4 to determine a Soil Recharge Potential for the site.

Example: Wetland Area is 80% Parnell soil and 20% Vallers soil.  
 Site Soil Recharge Potential is  $(0.8 \times 1.0) + (0.2 \times 0) = 0.80$ .

If a soil scientist is not available, a more qualitative method is described below in Table 9. For this qualitative method, if soil mapping is not available then the NWI water regime codes are used: PEMA = subindex of 1.0, PEMC = subindex of 0.5.

<b>Table 9. Qualitative Method to Determine Soil Recharge Potential.</b>	
<b>Measurement or Condition</b>	<b>Index</b>
Soil Map Unit has Recharge Potential $\geq 0.75$ and NWI water regime is A (e.g. PEMA) (i.e. wet meadow vegetative zone)	1.0
Soil Map Unit Recharge Potential is $0.5$ to $< 0.75$ and on-site dominant NWI water regime is A , <b>OR</b> Soil Map Unit Recharge Potential is $> 0.75$ and on-site dominant NWI water regime is C (e.g. PEMC) (i.e. shallow marsh and wet meadow vegetative zones exist)	0.67
Soil Map Unit Recharge Potential is $0.25$ to $0.75$ and NWI water regime is C	0.33
Soil Map Unit Recharge Potential is $< 0.25$ and NWI water regime is C	0.1

## Sediment ( $V_{SED}$ )

This variable is defined as the extent of sedimentation within the wetland from culturally accelerated sources.  $V_{SED}$  is estimated by determining the depth to the B horizon for four replicate, averaged sample pedons within the outer ponded depressional soils. Generally the soils that occur in the area where this is assessed are soils such as Tonka, Tetonka, and Typic or Cumulic Endoaquolls. B depths for the reference sites ranged from 0.0 to 112.0 centimeters ( $n=180$ ). The depth to B in reference standard sites varied throughout the reference domain from a maximum of 74 cm in the Cumulic soils in Iowa, to a minimum of 12 cm in the western PPR.

Because of the natural variability associated with soil formation, due primarily to climate across the PPR, reference sites were separated by Eastern (Minnesota, Iowa) and Western (South Dakota, North Dakota and Montana) sub-reference domains. For reference standard sites in the Eastern PPR the mean depth to the B horizon is 50cm, with a range of 28cm to 72cm. For reference standard sites in the Western PPR the mean depth to the B horizon is 32cm, with a range of 19cm to 45cm. Based on data from reference wetland sites, these intervals are assumed to be in the range of natural variation for PPR wetlands and reflect the reference standard condition. As depth to the B decreases, a linearly decreasing subindex down to 0.1 is assigned. This would be indicative of the condition of excessive sedimentation resulting in C horizons being described at the soil surface. Increases in B depth beyond the reference standard centimeter depth are assumed to be from culturally accelerated erosion rates from within the catchment or deposition of fill. Therefore, subindex scores are assumed to decrease inversely from this point. A variable subindex score of 0.0 is only assigned if the wetland has been filled to the point of no longer being a depression. None of the sampled reference sites meet this condition. The relationship of the metric to the sub-index score is presented in Figure 12.

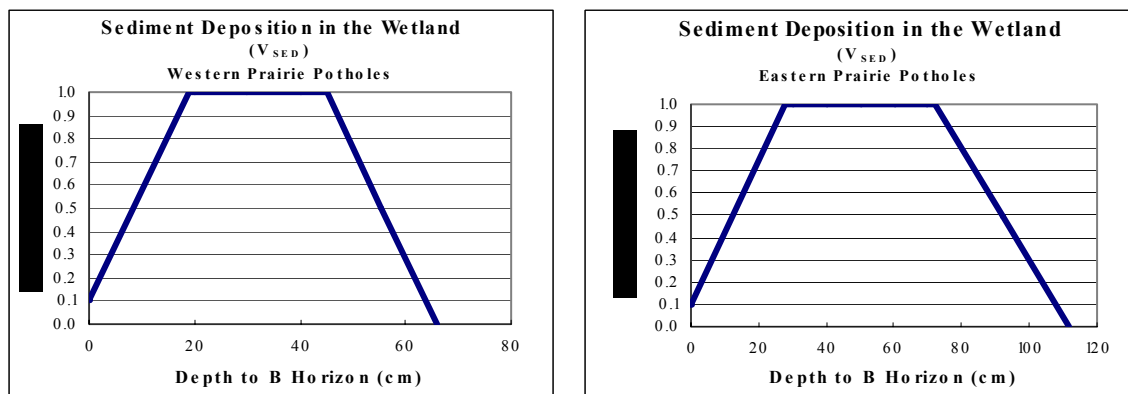


Figure 12. Relationship between the B horizon depth and the variable subindex for Western and Eastern Prairie Potholes.

## Soil Quality Index ( $V_{SQI}$ )

This variable represents the physical integrity of the upper 30cm of the soil (A or Ap horizon) within the outer ponded depressional soil. This variable was evaluated in soils such as Tonka, Tetonka, and Webster. This variable is not calibrated for soils with highly calcareous layers near the surface (i.e. Calciaquolls). "Better" soil quality values on similar soils under different management may be indicative of soils that have improved aggregation and greater

macroporosity, both of which may be related to greater soil biological activity (Lowery, et al. 1996). Water moving through the soil is important for maintaining plant growth, preventing erosion, carrying solutes into the soil biological “filter”, and maintaining wetland surface and soil water storage capability. Soil morphology has been used to estimate permeability (i.e. hydraulic conductivity (O’Neal 1952; Bouma and Hole 1971; McKeague, Wang, and Topp 1982; Kooistra et al. 1985) and, more recently, soil quality (Grossman et al. 2001).

This variable is measured by describing the soil structure, soil pores and rupture resistance (i.e. consistence) of the upper 30cm (Soil Survey Division Staff 1993). Numbers assigned for each characteristic are listed in Table 10. It is recommended that this procedure be used by experienced soil scientists, or by specifically trained personnel.

<b>Table 10.</b>						
<b>Soil characteristics evaluated in determination of the physical Soil Quality Index.</b>						
<b>-Assigned Value-</b>						
<b>Characteristic</b>	<b>0</b>	<b>1</b>	<b>1.5</b>	<b>2</b>	<b>2.5</b>	<b>3</b>
Pores	None	Few	Few to Common	Common	Common to Many	Many
Pore Continuity	None	Low		Moderate		High
Structure	Massive	Not Compound		Compound		
Consistence	Extremely Firm or harder	Firm & Very Firm		Friable		Very Friable

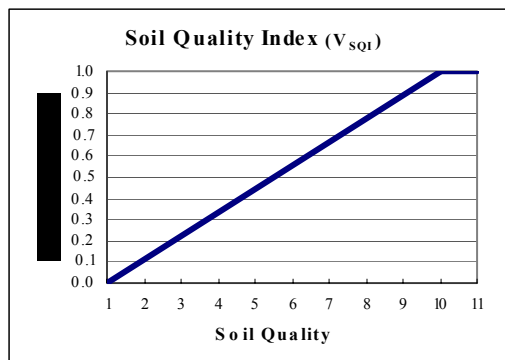


Figure 13. Relationship between the Soil Quality Index and the variable subindex.

The summation of these values from a soil description are then used to determine the physical Soil Quality Index (SQI). Data are averaged across replicates within the outer-temporary (i.e. wet meadow) depressional zone. The possible range of values for the SQI is a minimum of 0 (a parking lot) and a maximum of 11. Actual data range for reference data is 3 to 11. A variable subindex score of 1.0 was assigned for SQI values of  $\geq 10$ . The relationship of the metric to the sub-index score is presented in Figure 13.

Supporting the rationale for using the SQI as a surrogate for actual measures of organic carbon was verified by non-parametric statistics. The SQI was positively correlated to soil organic carbon (Figure 14). For  $n = 123$ , the Spearman Rank Correlation Coefficient indicated a significant correlation of SQI vs. percent organic carbon ( $r = .298$ ,  $p > .01$ ).

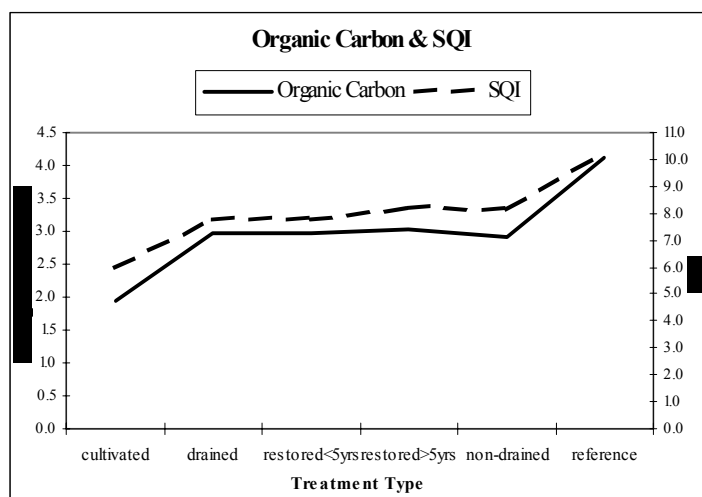


Figure 14. Relationship of the Soil Quality Index to soil organic carbon.

Exploratory data analyses of the treatment groups also indicated that the SQI is inversely related to soil bulk density (Figure 15). For  $n = 48$ , the Spearman Rank Correlation Coefficient indicated a significant correlation of SQI vs. bulk density ( $r = -.302$ ,  $p > .01$ ).

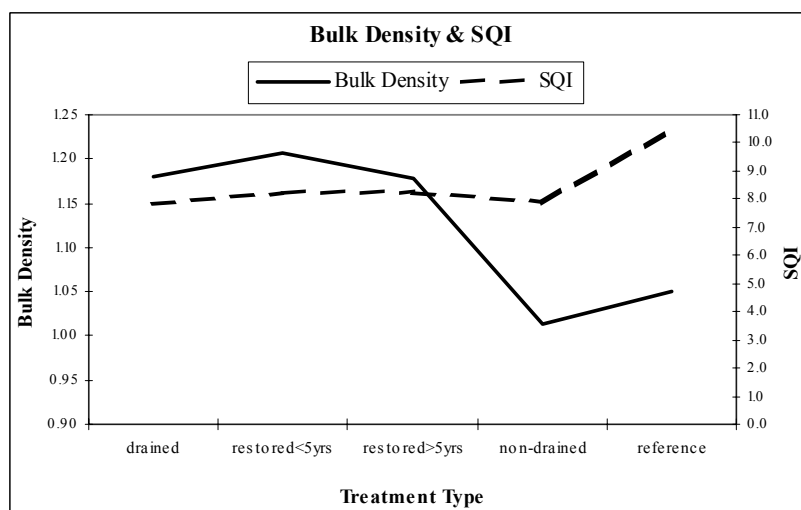


Figure 15. Relationship of the Soil Quality Index to Soil Bulk Density.

#### Soil Organic Matter ( $V_{SOM}$ )

This variable represents the amount of organic matter that is in the upper part of the soil profile. As with most all soil properties, this is a naturally variable property; however, organic matter content can be altered significantly by management practices. For example, drainage and removal of native plant communities can increase soil temperature and decrease soil organic matter content. Soil organic matter is an environmental characteristic that affects soil fertility (therefore plant community development), oxidation-reduction reactions, food webs, soil moisture retention and water conductivity.

Larson and Pierce (1991) describe SOM as the most important property for assessment of soil quality. For the purposes of soil organic matter assessment, the upper part (i.e. 30 cm) is most important because this is where most of the biogeochemical interactions that depend on soil organic matter take place. It is also the part of the soil profile most responsive to impact related changes in organic content (Van-Gestel, Ladd and Amato 1992). The organic matter in the upper part of the soil profile is reduced when soils are impacted by plowing, haying, over grazing, and drainage (Ross, Tate, and Cairns 1981; Blank and Fosburg 1989; Garcia and Rice 1994; Parton et al. 1987; Paul and Clark 1996).

This variable is measured in the wet meadow zone. This zone is associated with soils such as Tonka, Tetonka, and Typic or Cumulic Endoaquolls. The variable is measured either through direct laboratory analysis or indirectly through evaluation of soil physical properties in conjunction with undecomposed litter.

For direct measurement, samples are taken at 4 locations in the wet meadow zone at two depths (0 to 15 cm and 15 to 30 cm). A composite sample is made from the 4 and submitted for lab analysis. Step-by-step: identify proper zone, take 4 samples at roughly the 4 ordinal compass points for the 0 - 15 cm depth, mix together, and bag enough for lab analysis. Repeat for the 15 - 30 cm depth. Samples are analyzed for organic carbon by combusting at 1350° C and detection with infrared (Olness, personal communication). The relationship of the direct metric (n = 123) to the sub-index score is presented in Figure 16.

Although there is no doubt that soil organic content, as determined by laboratory analysis, is the preferred single method of evaluating soil condition, it is not likely that this procedure will be used often in rapid HGM assessment. Therefore, the following method was developed for use in estimating soil organic content.

Where direct measurement of soil organic matter is impracticable, a regression equation is provided from analyses of reference data. For n = 123 sites, mean % organic matter based on laboratory analysis is available. Indirect indicators were evaluated against actual measurements of mean % organic matter. Indicators used in the regression equation (independent variables) are the Soil Quality Index, the A horizon Darkness Index and litter depth (cm) in the wet meadow zone.

The Soil Quality Index is measured by describing the soil structure, soil pores and rupture resistance (i.e. consistence) of the upper 30cm (Soil Survey Division Staff 1993) as described previously.

The A- horizon Darkness Index metric is included in the regression equation as an indicator of soil organic matter. It is defined as the moist soil color of the uppermost A horizon (A1 or Ap1 horizon). Humified organic matter is the constituent that influences color of the A horizon. In the Munsell system of soil color, it is the soil color value that is most affected by the organic coloring agents.

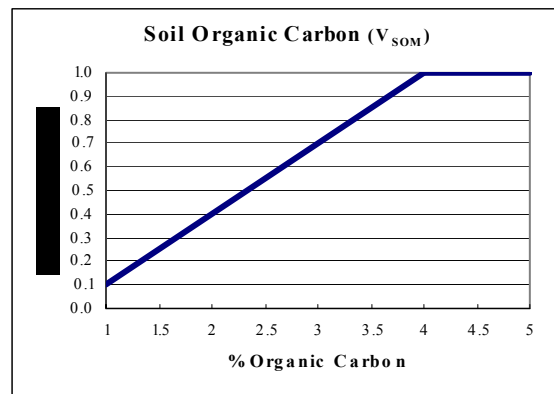


Figure 16. Relationship between the mean percent organic carbon and the variable subindex.

An A horizon darkness index (ADI) is derived using the following equation:  $ADI = (H + 2V + C)$ , H is the Hue (Where Hue of N = 0, all other Hues = 1), V is the Value and C is the Chroma. Values of 2.5 (on 2.5Y, 5Y and N hue color chips) are = to 2 in this procedure. The moist soil color is observed in four replicate soil profiles located in the outer depressional soil (i.e. temporary zone) and an "average" ADI is obtained. Two examples follow:

1) Four replicates of moist soil color are:

10YR 2/1,

10YR 2/2,

2.5Y 2.5/1, and;

10YR 3/1.

The weighted average ADI is:  $(6 + 7 + 6 + 8) / 4 = 6.75$

2) Four replicates of moist soil color are:

10YR 2/1,

N2.5/,

2.5Y 2.5/1, and;

N3/.

The weighted average ADI is:  $(6 + 4 + 6 + 6) / 4 = 5.5$

The ADI in reference sites varied throughout the reference domain from 4 to 12 (n=180).

Litter depth is included in the soil organic matter regression. It is defined as the depth (cm) of undecomposed litter (i.e. detritus). The measurements of litter thickness are made in the wet meadow zone. It is simply the measure of detritus that has not been incorporated into the soil profile. As with the SOM variable and other soil metrics, four replicate litter depths are determined and averaged for entry into the regression equation. Based on data collected at 180 reference sites, litter depths ranged from 0 to 14.5 cm .

In the prediction of the dependent variable (mean % organic matter), regression coefficients were first standardized for all independent variables to a mean of 0 and a standard deviation of 1. The resulting equation is:

$$\%OM \text{ (est.)} = 2.71 + .23 * (SQI) - .22 * (ADI) + .13 * (\text{litter depth})$$

## Hydrogeomorphic Variables

### Wetland Outlet ( $V_{OUT}$ )

This variable is the ratio of the elevation of the existing (or proposed) constructed outlet to the natural outlet. In rapid assessment it is not practical to measure the depth and duration of ponding. Such a measurement would be preferable; however, assessing the impact to ponding by alteration is more practicable. The elevation of the wetland boundary, basin center, natural outlet and any proposed or existing constructed outlet are measured and the ratio is then derived. For example, the natural outlet is 1.5 meters above the basin central elevation and the proposed project lowers that outlet by .25 meters.  $1.25/1.5 = .833$ , the variable sub-index score would be 0.83. Based upon analysis of 13 wetlands in the reference data set using SPAW (Saxton 2002), when the natural outlet is more than 1 meter above the wetland boundary, 1 meter is used as the

maximum elevation of the natural outlet. Any constructed outlet that is more than 1 meter above the wetland boundary elevation has little to no impact on the wetland ecosystem because water does not reach that elevation unless under extreme pluvial conditions. Also, this variable does not consider the capacity of the surface outlet. A ratio of 0.0 for  $V_{OUT}$  does not adequately represent the fact that water will be retained within a basin during pluvial cycles and extreme precipitation events. To represent this, the lowest ratio allowed is 0.05. For purposes of rapid assessment, the only time the  $V_{OUT}$  sub-index score would be equal to 0.0 is when the wetland storage capacity has been totally eliminated by fill or excavation. If user defined assessment objectives require more detailed hydrology information, scope and effect equations and hydrology tools can be used. This information is available at:

[http://msa.ars.usda.gov/ms/oxford/nsl/java/tools\\_java.html](http://msa.ars.usda.gov/ms/oxford/nsl/java/tools_java.html)

Features such as drainage ditches, tile intakes, and deep road ditches within the hydric soil footprint, and alteration of natural outlets or overflows are all included in the definition of wetland outlet. Fill that is placed within the wetland is also included when assessing this variable. Users will have to determine the percentage of storage that is lost by the placement of fill. Excavations, such as dugouts for livestock, are also included when assessing this variable. An estimation of the volume of the wetland impacted is entered into the calculation worksheet. (e.g. a dugout is 25% of the volume of the original wetland, 25 is entered into the calculation sheet). The volume of an excavated pit, fill, or wetland, can be estimated by many means, including use of Global Positioning Systems, Geographic Information System technology or standard field survey techniques. The prismoidal formula uses surface areas, mid-depth and bottom depth, along with the average depth to estimate the volume. Other formulations are also available and can be used (e.g. bowl shape,  $V=0.52*d*(3a^2 + d^2)$ , where,  $d$  = depth in center, and  $a$  = radius of area). Users should consult the Engineering Field Handbook, Chapter 11, pages 11-44 for more detailed guidance. This information can be found at:

<http://www.info.usda.gov/CED/ftp/CED/EFH-Ch11.pdf>

Alterations can occur singly or in various combinations and may have a significant effect on wetland hydrology. Alterations that extend only into the wet meadow zone of a seasonal wetland often allow some ponding to remain. Those that are situated or extend into the deepest portion of the wetland generally drain the entire area.

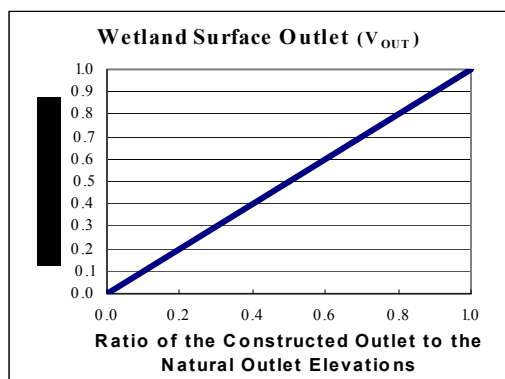


Figure 17. Relationship between the ratio of the constructed outlet elevation to the natural outlet elevation and the variable subindex.

Where detailed basin morphometry data is available for seasonal wetlands ( $n=87$ ) in the reference data set, the mean wetland volume available for storage is 64% in the temporary zone, and 36% in the seasonal zone. This means approximately 2/3rds of a seasonally inundated prairie pothole wetlands volume exists in the shallower temporarily inundated (wet meadow zone) portion of the wetland. The relationship of the metric to the sub-index score is presented in Figure 17.

### Subsurface Outlet ( $V_{\text{SUBOUT}}$ )

This variable is defined as the presence of constructed drainage outside the boundary of the wetland or subsurface drainage (e.g. tile) within the wetland. The effectiveness of drainage outside the wetland is based upon features such as: distance of drain, capacity of drain, depth below wetland elevation and soil permeability (hydraulic conductivity). For a more complete discussion see U.S. Department of Agriculture (1997). Tile drainage beneath or adjacent to the wetland affects the ability of a wetland to maintain saturated, anaerobic conditions, increases peak flows downstream (Moore and Larson 1980) and can increase movement of elements and compounds (such as pesticides and nitrogen) downstream. The effectiveness of tile drainage is based upon characteristics that include: tile spacing, depth, diameter, and soil permeability (hydraulic conductivity). The relationship of the categorical condition to the index score is presented in Table 11.

<b>Table 11.</b> <b><math>V_{\text{SUBOUT}}</math> categorical variable.</b>	
Measurement or Condition	Index
Subsurface flow is not impacted or if there is a nearby subsurface/surface drainage feature it is greater than 150 feet from wetland edge.  -OR- Wetland has been restored to natural outlet elevation and there is no evidence of subsurface flow (e.g. hydrophytic vegetation, water seepage, etc.) within 50 feet of the downstream toe of the natural outlet.	1.0
Subsurface / surface drainage feature is between 75 and 150 feet from the wetland edge and is greater than 3 feet below the top elevation of the temporary (i.e. wet meadow) zone.  -OR- Wetland has been restored with the use of a ditch plug and there is no evidence of subsurface flow (e.g. hydrophytic vegetation, water seepage, etc.) within 50 feet of the downstream toe of the ditch plug.	0.75
Subsurface/surface drainage feature is between 75 and 25 feet from wetland edge and greater than 2 feet below the top elevation of the temporary (i.e. wet meadow) zone.  -OR- Wetland has been restored with the use of a ditch plug and there is evidence of subsurface flow (e.g. hydrophytic vegetation, water seepage, etc.) within 50 feet of the downstream toe of the ditch plug.	0.5
Subsurface/surface drainage feature is within 25 feet of wetland edge and greater than 2 feet below the top elevation of the temporary (i.e. wet meadow) zone.  -OR- Wetland has poorly functioning tile within the wetland basin (i.e. saturation conditions still exist within the basin).	0.25
Properly functioning tile or pattern tile within the basin. Almost all water moving through soil profile below the wetland is intercepted by drainage tile.	0.1

### Wetland Source Area ( $V_{\text{SOURCE}}$ )

This variable is a measure of the percent change in the catchment area surrounding a wetland. Change can be an increase, decrease, or combination of both. In some catchments it is not unusual to have both an increase to the catchment along with a decrease due to a combination of the various alterations. Alterations in the catchment have a direct effect on the amount of water flowing off the landscape into the wetland. In some instances (e.g. land leveling for irrigation or consolidated drainage) an actual increase in catchment size has resulted. More commonly, the placement of drainage ditches, tile drainage, county roads, and other alterations within the catchment have intercepted or diverted flows away from wetlands. By using soil survey maps, aerial photos, and topographic maps the original, or historic catchment boundary can be delineated with relative accuracy. Then, additions or reductions to the catchment are determined to find the percent change which has occurred. Index values are scored categorically, based on the appropriate description of catchment condition as indicated below in Table 12.

<b>Table 12.</b> <b>V<sub>SOURCE</sub> categorical variable</b>	
Measurement or Condition	Index
Minimal alteration of the upland catchment source area through structural surface alterations (e.g. terraces, road ditches, etc.), subsurface alterations (e.g. tile drainage, ditches), or irrigation additions. $\geq 90\%$ of catchment area is intact.	1.0
Surface alterations of the upland catchment source area which impact overland flow into the wetland have occurred, however, no tile drainage in the catchment which "de-waters" the wetland being assessed and / or no irrigation additions. 75 to $< 90\%$ of catchment area is intact.	0.75
Upland catchment source area is changed to alter the dominant surface and / or subsurface flow path of water to the wetland (e.g. drainage or irrigation return). However, the alteration(s) does not change the wetland water regime class. 25 to $< 75\%$ of catchment area is intact.	0.50
Upland catchment source area is changed to alter the dominant surface and / or subsurface flow path of water to the wetland (e.g. drainage or irrigation return) - <b>and</b> - alteration changes the wetland water regime class. (e.g. a seasonal wetland is changed to semi-permanent or temporary). $< 25\%$ of catchment area is intact.	0.10
The upland catchment source area is extremely altered such that almost all surface and sub-surface water flow to the wetland is eliminated. (e.g. tile drainage intercepts water and diverts it from wetland, urbanization moves water to another area, etc.)	0.00

#### Wetland Edge Index (V<sub>EDGE</sub>)

The variable is a measure of the degree of shoreline irregularity expressed as ratio of the perimeter of the assessment wetland as compared to the perimeter of a circular wetland of equal area. The closer this ratio is to 1, the more circular the wetland. A larger ratio means the shoreline (edge) is more crenulated. Rate of water loss from prairie potholes varies directly with length of shoreline per unit area and inversely with size of individual sloughs; and, hence, with higher ratios, there is a higher potential for recharge (Millar 1971). Shoreline irregularity also represents the ecotonal overlap between two communities (edge effect), displaying a distinct species composition or abundance as compared to adjacent patches. A modified shoreline irregularity index as adapted from Wetzel (1975) was used in computation of this variable. The metric for this variable is calculated as follows:

$$V_{EDGE} = \text{wetland perimeter} / 2 * \sqrt{\text{wetland area}}$$

Reference data analysis indicated a range of values from 1.0 to 3.4. Mean value was 2.15. Based on measurements at reference standard sites, the 1.0 variable subindex score was set at 2.5. The relationship of the metric to the variable sub-index score is assumed to be a linear relationship (Figure 18).

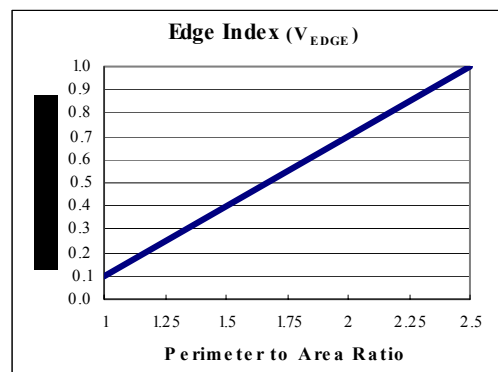


Figure 18. Relationship between the metric and the variable subindex.

#### Catchment : Wetland Ratio (V<sub>CATCHWET</sub>)

This variable is the ratio of catchment size to wetland size. Wetlands that have a higher catchment to pond ratio are more likely to contribute water to recharge (Arndt and Richardson 1988). The

number is calculated using the formula:  $(1/\text{wetland area}) \times (\text{area of the catchment})$ . The catchment area includes the wetland. Catchment: wetland ratios (n=155) in the reference data range from a low of 1.03 in Minnesota to a high of 17.70 in Montana. The mean catchment: wetland ratio (n=155) is 4.02. Arndt and Richardson (1988) suggest that wetlands with a ratio  $\geq 5.7$  are recharge wetlands and ratios as low as 4.5 can still indicate recharge conditions in a flow through wetland. Hayashi, van der Kamp, and Rudolph (1998a) reports that summer-time decline of water levels in a seasonal small wetland with a catchment: wetland ratio of 10:1 essentially represents recharge of groundwater. A sub-index of 1.0 is assigned to ratios  $> 5.5$ . The relationship of the metric to the variable sub-index score is assumed to be a linear relationship (Figure 19).

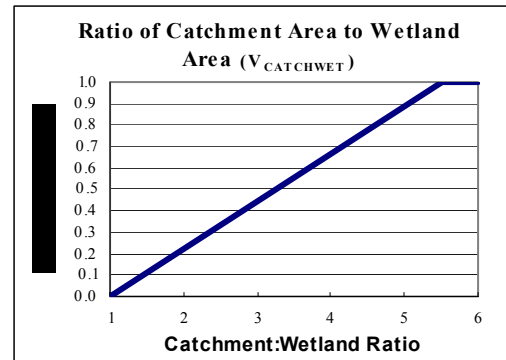


Figure 19. Relationship between the ratio of catchment area to wetland area and the variable subindex.

## Land Use and Landscape Variables

### Upland Land Use ( $V_{UPUSE}$ )

This variable represents the condition of the terrestrial cover, as represented by land use/land cover categories within the present-day catchment of the wetland being assessed. It is measured by determining an area based weighted average runoff curve for the catchment. Curve numbers(weights) corresponding to reference data land use categories are provided in Table 13.

<b>Table 13</b> <b>Runoff curve numbers for <math>V_{UPUSE}</math></b>	
<b>Upland Land Use "Condition"</b>	<b>Curve Number Hydrologic Soil Group B</b>
Urban, semi-pervious, or impervious surface	98
Feedlot	90
Conventional tillage row crop	79
No-till row crop/ high residue crops	77
Row crop - contoured and terraced	72
Conventional tillage small grain	75
No-till small grain/ high residue crops	73
Small Grain - contoured & terraced	71
Minimum till in a grass/legume rotation	72
Farmsteads	74
"Permanent" hay land	69
Rangeland - Native or non-native species, overgrazed, high amount of bare ground, low plant vigor and evidence of soil erosion (e.g., gullies, rills, etc.)	79
Rangeland - Native or non-native species, often overgrazed, some bare ground, low plant vigor	74
Rangeland dominated by non-native species under some type of management -OR- Rangeland - native species with fair grazing management such as season-long grazing at slight or moderate intensity -OR- Rangeland - idle grassland cover. (Includes idle native range & CRP)	69
Native prairie that allows for adequate plant recovery time between vegetation removal	61

If more detail is required, the user has the option of using the above Table or consulting the Engineering Field Handbook's curve numbers. Source information for runoff curve numbers can be found at:

<http://www.nrcs.usda.gov/technical/ENG/efh.html>

Based on data from reference wetlands, a variable sub index score of 1.0 is assigned for a weighted average score of  $\leq 61$ . Values for the reference sites ranged from 61 to 79, mean value was 69.6 for  $n = 180$ . The relationship of the metric to the variable sub-index score is assumed to be a linear relationship (Figure 20).

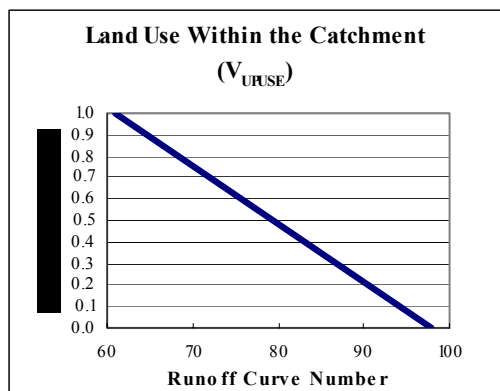


Figure 20. Relationship between the Curve Number and the variable subindex.

#### Wetlands Proximity ( $V_{WETPROX}$ )

This variable is a measure of the proximity of the assessment wetland to other palustrine wetlands. This is a critical landscape variable that affects the ability of species and propagules to move from one wetland to another. It is also used as an indicator of the wetland complex condition, with emphasis at a finer scale of resolution as compared to the other landscape variables. As illustrated in Figure 20,  $V_{WETPROX}$  is measured as the mean inter-wetland distance (edge to edge) from the assessment wetland to the nearest 5 wetlands. These distances are then averaged.

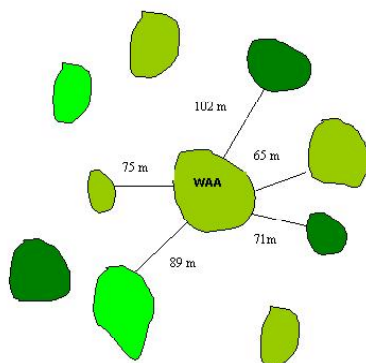


Figure 20. Example of inter-wetland distance measurements for  $V_{WETPROX}$ .

Reference data ranged from 58 m to 862 m, with a mean of 209 m. Based on conditions measured at reference standard sites, this variable achieved a maximum score of 1 as the average inter-wetland distance approached  $\leq 80$  m. Alternately, the variable subindex score equals zero when the average inter-wetland distance approached 330 m.

The relationship of the metric to the variable sub-index score is assumed to be an inverse linear relationship (Figure 21).

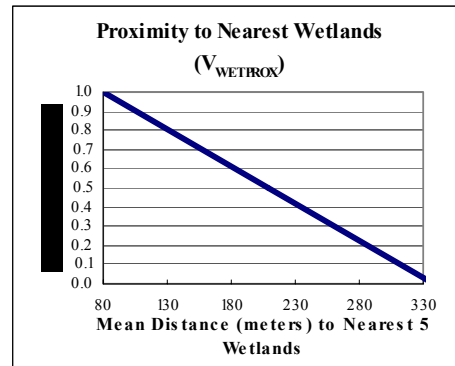


Figure 21. Relationship between the mean inter-wetland distance and the variable subindex.

#### Wetland Density in the Landscape Assessment Area (V\_WETAREA)

V wetarea is used as a measure of the condition of the wetland complex associated with the assessment wetland. The area of palustrine wetlands (hectares) occurring within a wetland complex is measured. A Landscape Assessment Area (LAA) was circumscribed from a 1.6 kilometer radius from the reference sites' centroid. The LAA was 8.1 km<sup>2</sup> and serves as the wetland complex for purposes of analyses.

Both polygon and point data from source NWI digital data were used. Palustrine point data were assigned an area value of .1 ha and included in calculations. Wetland complex area measurements ranged from approximately 4 to 385 ha. Mean area for the reference sites' complex (n = 180) was 97 ha. The reference standard condition was defined as  $\geq$  to 160 ha. The relationship of the metric to the variable sub-index score is assumed to be a linear relationship (Figure 22).

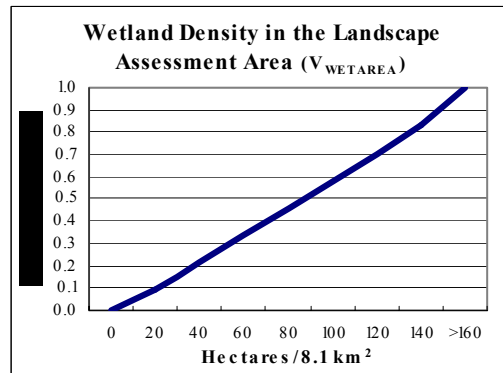


Figure 22. Relationship between wetland area in the LAA and the variable subindex.

#### Number of Basins in the Landscape Assessment Area (V\_BASINS)

This variable is the number of palustrine wetlands within the LAA. Basin counts were derived from recoded NWI polygon data. Point data were included in the basin counts. The LAA was circumscribed from a 1.6 kilometer radius from the reference site's center. The LAA area evaluated was 8.1 km<sup>2</sup> and serves as the wetland complex for purposes of analyses. For the reference data set, mean number of basins was 120 / 8.1 km<sup>2</sup> with number of basins ranging from

6-365 / 8.1 km<sup>2</sup> ,. The reference standard was defined as > 200 / 8.1 km<sup>2</sup>. The relationship of the metric to the variable sub-index score can be found in (Figure 23).

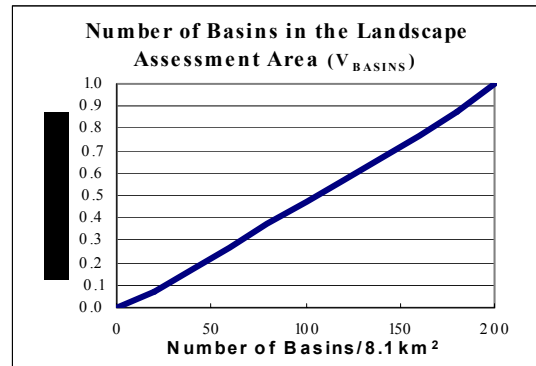


Figure 23. Relationship between the number of basins in the LAA and the variable subindex.

#### Landscape Habitat Fragmentation (V<sub>HABFRAG</sub>)

This variable is the sum of the linear extent of roads and drainage features (km) within the LAA. It is used to account for fragmentation within the wetland complex. Wetlands are often intersected by roads, thereby fragmenting the historic basins. Roads, ditches and drainage features contribute to alteration of basins hydrodynamics, alter groundwater flow patterns, reduce storage, alter connectivity, and reduce habitat suitability.

The LAA was circumscribed from a 1.6 kilometer radius from the reference site's centroid. The LAA was 8.1 km<sup>2</sup>. Roads data were derived from the U.S. Census Bureau 1:100,000 scale data. Linear attributes were from NWI data. Linear attributes include both the "d" or "x" modifier (partly drained and excavated respectively, (Cowardin et al. 1979).

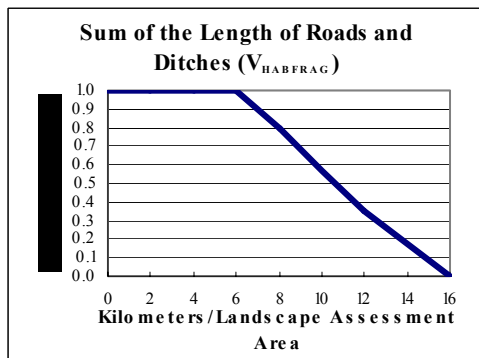


Figure 24. Relationship between the length of linear features in the LAA and the variable subindex.

For the reference data set, mean length of linear features was 10.6 km / 8.1 km<sup>2</sup> with values ranging from 1.1 - 22.1 km / 8.1 km<sup>2</sup>. The reference standard condition for V<sub>HABFRAG</sub> was < or = 6.0 km / 8.1 km<sup>2</sup>. The relationship of the metric to the variable sub-index score can be found in Figure 24.

## Prairie Pothole Wetland Functions

The following sequence is used in articulation of the selected functions.

Definition: defines the function and identifies an independent quantitative measure that can be used to validate the functional index.

Rationale for selecting the function: provides the rationale for why a function was selected and discusses onsite and offsite effects that may occur as a result of lost functional capacity.

Characteristics and processes that influence the function: describes the characteristics and processes of the wetland and the surrounding landscape that influence the function.

Functional capacity index: describes the assessment model from which the functional capacity index is derived and discusses how model variables interact to influence functional capacity.

### **Function 1: Water Storage**

#### **Definition**

This function reflects the capacity of a prairie pothole wetland to collect and retain inflowing surface water, direct precipitation, and discharging ground water as standing water above the soil surface, pore water in the saturated zone, and/or soil moisture in the unsaturated zone. A potential independent quantitative measure of this function would be the amount of water stored in the wetland per a given time (e.g. hectare-meters/year).

#### **Rationale for selecting the function**

This function is critical to the maintenance of the wetland and is often considered as the main forcing function for all other wetland processes. Water storage in PPR wetlands is important for three reasons. First, water that is delayed or stored in the wetland reduces the amount of runoff downslope thereby ensuring a decrease in flood crests down gradient. Second, it guarantees that sufficient moisture is available to allow the development and maintenance of hydric soils and appropriate hydrophytic plant communities. The presence of these plant communities ensures wildlife habitat is available for a variety of species, both resident and migratory. Subsurface water storage may also benefit crop production and wildlife production, because during the nongrowing season period, subsurface storage of water becomes a crucial determinant of crop yields the following growing season (Schroeder and Bauer 1984). And finally, water storage supports the biogeochemical processes that occur in wetlands such as the removal of nutrients and particulates. This process results in improved water quality.

Prairie pothole basins have considerable potential for storing runoff. In the large wetland complexes of Salyer National Wildlife Refuge of North Dakota, undrained, mostly unconnected wetlands were reported to be storing 58% of the inflow, plus all local runoff (Malcolm 1979). In the Devils Lake Basin of North Dakota, wetland basins store between 41% of the runoff from severe (100-year) storm events, and up to 72% of the runoff from smaller events (Ludden, Frink, and Johnson 1983). In the Pembina River Basin of North Dakota, each undrained wetland can store up to 0.123 hectare-meters (1 acre-foot) of runoff (Kloet 1971), a figure also supported by

the data of Hubbard and Linder (1986) from 213 wetlands in northeastern South Dakota. Seasonal wetlands in the reference data set store approximately 0.1476 hectare-meters (1.2 acre feet) of water.

Prairie pothole wetlands facilitate detention of runoff because many lack well-defined surface water outlets, and between basins subsurface flows in glacial till are slow (e.g., 0.05 meters/day, Tipton et al. 1972). When runoff is detained in a regionally dispersed manner by pothole basins, pulses of water that eventually enter downstream areas in most cases are staggered (desynchronized). This broadens the storm hydrograph and reduces streamflow peaks. Wetland basins in the reference data set store as much as 40% of their water in the catchment area beyond the jurisdictional wetland boundary.

### Characteristics and processes that influence the function

The characteristics and processes that influence the capacity of a pothole wetland to store water over an extended period are related natural factors such as climate, geomorphic characteristics, soils, and vegetation. Additionally, anthropogenic factors play a significant role on many landscapes in the Prairie Pothole Region. This includes hydrogeomorphic modification of the wetland through ditching or the placement of tile drainage, and modifications of the surrounding landscape that can alter the timing and amount of water reaching the wetland. Kittelson (1988) reports that changes in peak flows attributable to a depressional wetland varies according to the interaction between outlet capacity, storage available within the site, and the amount of water coming into a wetland.

The characteristics associated with the performance of this function focus on land use as it impacts volume and timing of water entering the wetland, the volume of the wetland available for storage, the condition of the soils and plants (evapotranspiration, seepage, and soil storage), and activities that reduce retention time (e.g. artificial drainage). Activities above or within the wetland affect the rate and quantity of surface and subsurface water entering and leaving the wetland. Land use activities also affect erosion up-slope and sediment import into the wetlands. An increased sediment load will decrease the wetland's capacity to store water, sometimes nearly eliminating storage capacity (Luo et al. 1997). Finally, the elevation and capacity of any constructed outlet below the storage boundary directly impacts the height of the water level and, therefore, the ability of the depression to capture and retain water.

Although accumulation and retention of sediments and particulates is a recognized function of depressional wetlands resulting in improved water quality, it has a negative affect on wetland hydrology. Most PPR wetlands are closed basins, thus sediment inputs are derived primarily from wind and water erosion of upland soils within the catchment. Upland land use affects the movement of water, sediment, and pollutants into the wetland. Generally, the higher the percentage of catchment under perennial cover, the better the condition of the wetland. Properly managed perennial cover helps to slow the movement of water downslope, which aids in the filtering of sediments and entrapment of pollutants. The chief negative impact to wetlands of accelerated sedimentation is loss of volume due to filling. In the playa wetlands of Texas, Luo et al. (1997) found that basins in cultivated catchments had lost nearly all of their original volume due to filling by sediment. Precipitation that was once lost through evapotranspiration or infiltration to groundwater before entering wetlands with grassland catchments enters via spates of surface runoff from tilled catchments (Euliss and Mushet 1996). The accelerated runoff often brings erosional sediments from the surrounding landscape contributing to filling the basin with soil. In addition to the alteration of hydrologic inputs, the loss of basin volume from siltation

reduces the water storage capacity and flood attenuation benefits of wetlands (Brun et al. 1981; Ludden, Frink, and Johnson 1983). Gleason (2001) estimated that over a 200 year time span, 50% of prairie pothole wetland storage volume would be eliminated due to accelerated sedimentation in cultivated catchments, vs. a 20% loss of volume for wetlands in perennially vegetated catchments.

## Functional Capacity Index

The assessment model for calculating the FCI for the function “Water Storage” is as follows:

$$FCI = \sqrt{\left( \text{Minimum of } V_{OUT}, V_{SUBOUT} \right) \times \frac{\left[ V_{SED} + \frac{(V_{SOURCE} + V_{UPUSE})}{2} \right]}{2}}$$

In the model, the variables having the greatest impact on the ability of a wetland to perform this function are anthropogenic drainage features (surface outlets or tile drains). Alterations that perform year round to remove water from the wetland have a major impact on hydrology. Simply stated, if the wetland has been so hydrologically modified that it is completely drained (subindex = 0), then the wetland no longer has the capacity to perform the function “Water Storage” and the FCI equals zero.

$V_{SED}$  is used to estimate the amount of storage reduction due to sedimentation. The variables  $V_{UPUSE}$  and  $V_{SOURCE}$  are used to estimate the timing and amount of runoff coming into the wetland. If the source area is changed, there is more or less water coming into the system so the function lessens. If the land use in the catchment is less than reference standard, water can come in “spates” and decrease the ability of an individual wetland to perform the water storage function.

## Function 2: Groundwater Recharge

### Definition

This function is the capacity of a prairie pothole wetland to move surface water downward into local or regional groundwater flow paths. Groundwater recharge is the entry into the saturated zone of water made available at the water table surface, together with the associated flow away from the water table within the saturated zone (Freeze and Cherry 1979). A potential independent, quantitative measure of this function is the volume of water lost to groundwater per unit area per unit of time ( $m^3/ha/time$ ). Usually this is measured or estimated on a net annual basis.

### Rationale for selecting the function

Traditionally groundwater recharge has been listed as one of the most important attributes of wetlands (Carter et al. 1979; Mitsch and Gosselink 1993). Water that infiltrates and recharges groundwater contributes to the local and regional groundwater flow net, thus contributing to higher base flows and improved distribution of seasonal flows (Ackroyd, Walton, and Hills 1967). Recharge is important for replenishing aquifers used for water supply. Recharge from

wetlands in a 1600-acre prairie pothole area was estimated to provide 12 acre-feet to the aquifer, enough to support 1,699 head of cattle for one year (Hubbard and Linder 1986). Estimates of recharge from small prairie wetlands to regional aquifers as summarized by Hayashi, van der Kamp, and Rudolph (1998b) suggests that small pothole wetlands may be the main source of water to regional aquifers.

#### Characteristics and processes that influence the function

The attributes of depressional wetlands that allow them to recharge groundwater are not completely understood. Many studies indicate that wetlands, especially in humid climates, are principally discharge areas (Lissey 1971). The complexities of groundwater interactions with depressional wetlands make it difficult to model groundwater functions. The recharge / discharge function of pothole wetlands has been shown to change seasonally (Winter and Carr 1980; Winter and Rosenberry 1995), annually, cyclically through drought and pluvial cycles (Lissey 1971) and some pothole wetlands have been shown to function as both hydrologic sources and sinks simultaneously (Williams 1968; Winter and Rosenberry 1995).

One of the criteria for the classification of this regional subclass is that these are primarily groundwater recharge wetlands. However, even within the narrowly defined subclass natural climatic and geomorphic characteristics result in presumed differences in this function on a regional scale. Additionally, anthropogenic disturbances can dramatically affect the ability of a given pothole wetland to perform this function.

The ability of any portion of the earth's surface to be a groundwater recharge area can be simplified to two components: hydraulic head and hydraulic conductivity (Freeze and Cherry 1979). Hydraulic head is provided by two characteristics, the elevation of the wetland relative to the groundwater surface (elevation head) and the mass and pressure of water (pressure head). In the depression focused recharge (Lissey 1968) that occurs in prairie potholes, the pressure head is provided by the ability of the basin to collect and pond water (both within and above the wetland "boundary") and the elevation head is generally dependent upon the basins position in the groundwater flow path. The overall hydraulic conductivity is dependent upon soil infiltration and hydraulic conductivity and by the underlying geologic materials (Winter and Rosenberry 1995).

The variables associated with the performance of this function focus on hydrogeomorphic characteristics that affect the hydraulic head and water movement rates. Characteristics that affect the ability of a pothole wetland to transmit surface water to groundwater include soil morphology and alterations to the plant community that impact evapotranspiration and seepage rates (Eisenlohr 1975). Seepage outflow rates are much higher in ephemeral and temporary potholes than rates in seasonal and semi-permanent potholes (Sloan 1970). Smaller temporary wetlands in higher landscape positions are more likely to function as recharge sites and more permanent depressional wetlands in topographic lows are more likely to be sites of groundwater discharge (Eisenlohr and Sloan 1968; Winter 1989).

Wetlands that have a higher catchment to pond ratio are more likely to contribute water to recharge (Arndt and Richardson 1988). The variable that represents this phenomenon is  $V_{\text{CATCHWET}}$ . This variable is also considered to reflect water chemistry which is an indication of recharge. Potholes with water of low conductivities are indicative of net seepage outflow condition and water of high conductivity is indicative of net seepage inflow. (Eisenlohr and Sloan 1968; Rozkowski 1967). In the realm of rapid assessment it is not practical that a one-time measure of water chemistry can be used for several reasons. The principal reasons are that there may not be any water in the pothole wetland at the time of assessment, and temporal changes in

surface water chemistry can be significant. It has been shown that prairie pothole soil types can provide an indication of water chemistry and recharge potential (Arndt and Richardson 1988). Use of the soil classification as it relates to recharge potential is the variable used ( $V_{\text{RECHARGE}}$ ).

Basins with high shoreline to pond ratios also may be an indication of recharge because downward percolation of water often occurs on wetland edges. The higher perimeter per unit of surface area of smaller wetlands allows more water to spread out from depressional wetlands (Millar 1971). Rate of water loss from prairie potholes varies directly with length of shoreline per unit area and inversely with size of individual sloughs. The  $V_{\text{EDGE}}$  variable is used for defining the relationship of shoreline to area.

Land use activities also affect erosion up-slope and sediment import into the wetlands. An increased sediment load will decrease the wetland's capacity to store water. The degree of sedimentation is captured by the  $V_{\text{SED}}$  variable. Undisturbed soil conditions within the wetland are closely related to water movement through the ability of soil to allow water to infiltrate and move downward. This soil condition is described in the  $V_{\text{SQI}}$  variable. Alterations of the plant community have been shown to affect seepage rates (Eisenlohr 1975; Shjeflo 1968). The  $V_{\text{VEGCOMP}}$  variable is used to reflect this. Local groundwater is directly impacted by the presence of nearby subsurface drainage (e.g., ditches, tile drains, etc.), which, in turn, impacts surface water and, therefore, the amount of seasonal water that the depression can capture and hold. The  $V_{\text{SUBOUT}}$  variable reflects this aspect of the function. Finally, the elevation of the surface outlet directly impacts the height of the water level and, therefore, the ability of the depression to provide the pressure head necessary for depression focused recharge. If a wetland that recharges groundwater is drained, the recharge function of the wetland will no longer exist (Winter 1989). The  $V_{\text{OUT}}$  variable is used to reflect this aspect of the function.

### Functional Capacity Index

The assessment model for calculating the functional capacity index (FCI) is as follows:

$$\text{FCI} = \sqrt{(\text{Minimum of } V_{\text{OUT}}, V_{\text{SUBOUT}}) \times \frac{\left[ \frac{(V_{\text{RECHARGE}} + V_{\text{EDGE}} + V_{\text{CATCHWET}})}{3} \right] + \left[ \frac{(V_{\text{SQI}} + V_{\text{SED}})}{2} \right]}{2}}$$

In the model, the capacity of a depressional wetland to recharge groundwater depends on several characteristics. In the first part of the model, the lesser of  $V_{\text{OUT}}$  or  $V_{\text{SUBOUT}}$  indicate the drawdown of water by surface or subsurface drainage which decrease pressure head or intercepts the water before it can recharge groundwater. If the outlet has the capacity to remove surface water completely, the subindex would equal 0.0. Or, if the subsurface drainage intercepts all water below the wetland, the subindex would equal 0.0. In these cases, the corresponding FCI would also be equal to 0.0.

$V_{\text{RECHARGE}}$ ,  $V_{\text{EDGE}}$ , and  $V_{\text{CATCHWET}}$  are all hydrogeomorphic variables that reflect a prairie potholes natural affinity to recharge groundwater. The  $V_{\text{SQI}}$  and  $V_{\text{SED}}$  variables are used to assess near surface alteration of the soils hydraulic conductivity and basin storage.

### **Function 3: Retain Particulates**

#### **Definition**

Retain particulates is defined as the capacity of a wetland to physically remove and retain inorganic and organic particulates  $>0.45\ \mu\text{m}$  (Wotten 1990) from the water column. A potential independent measure of this function is the amount of particulates retained per unit area per unit time (i.e.,  $\text{g/m}^2/\text{yr}$ ).

#### **Rationale for Selection of Function**

Sediment retention by wetlands is often described as a water quality benefit (Boto and Patrick 1978). Sediment deposition is a natural geologic process that is maintained over thousands of years. However, accelerated sedimentation may be the most detrimental impact on depressional wetlands. Retention applies to particulates arising from both on-site and off-site sources. The retention function contrasts with the Removal of Elements and Compounds function because of the emphasis on physical processes (e.g., sedimentation and particulate removal) rather than elements and compounds, many of which are in the dissolved state. There are two primary benefits of this function. First, the removal of particulates reduces the load of particle bound nutrients, heavy metals, pesticides, and other pollutants into groundwater, and nearby rivers and streams. Second, at natural sustainable levels, these inputs are necessary for the overall maintenance of the nutrient budget and associated characteristic plant and animal communities of prairie pothole wetlands.

#### **Characteristics and Processes that Influence the Function**

The characteristics and processes that influence a depressional wetland's ability to perform this function can be divided into two groups. The first deals with the sources and mechanisms by which particulates are transported, and / or prevented from entering into the wetland. Sediment inputs into prairie potholes are derived primarily from wind and water erosion of soils in the immediate catchment and adjacent upwind landscapes. The second group of characteristics and processes relate to the immobilization of the particulates that are transported into the wetland. The primary characteristic that causes sediment accumulation in prairie pothole wetlands is landscape position. Because most prairie pothole wetlands occur in surficially closed basins they become "targets" for the retention of water-borne sediment. Vegetation structure also influences the ability of the wetland to trap sediment, both from water and wind erosion. Accumulation of sediment in depressional wetlands decreases wetland volume (Luo et al. 1997), decreases the duration wetlands retain water (Gleason and Euliss 1998), and changes plant community structure by burial of seed banks (van der Valk and Pederson 1989; Jurik, Wang, and van der Valk 1994; Wang, Jurik, and van der Valk 1994). Sediment retention of elements and compounds occurs through burial and chemical precipitation (e.g., removal of phosphorus by iron III). Dissolved forms may be transported with the particles through sorption and chelation (i.e., heavy metals mobilized with humic and fulvic compounds). Imported sediment can undergo renewed pedogenesis on site, which potentially involves weathering and release of elements that were previously inaccessible to mineral cycling.

Particulates are transported into pothole wetlands from several sources. They include dry deposition and precipitation from the atmosphere, overland flow from adjacent uplands and occasional overflows connecting wetlands during wet periods of high storage (Adomaitis, Kantrud, and Shoesmith 1967; Leonard 1988; Grue et al. 1989; Winter and Rosenberry 1995; Waite et al. 1992). Atmospheric sources are assumed to account for a relatively small amount of

the total particulates that typically impact pothole wetlands. However, in areas of intense agriculture, atmospheric inputs due to sediment deposition may be significant (Adomaitis, Kantrud, and Shoesmith 1967; Frankforter, 1995). The dominant mechanisms for the input and output of particulates among pothole wetlands is surface sources such as overland flow, surface connections between wetlands during wet periods, and man-made ditches. These sources are a function of wetland basin morphology (e.g., catchment size, slope gradient, and natural or man-made surface connections).

Dense vegetation cover reduces surface water velocities and allows for greater infiltration, filtration of particulates, and soils are less likely to erode. Therefore, uplands with dense vegetation cover and wetlands with buffers of perennial vegetation around them will supply fewer particulate inputs to the wetland than uplands with sparse vegetation cover (Neely and Baker 1989; Luo et al. 1987; Dieter 1991; Gleason and Euliss 1998). Martin and Hartman (1987) found prairie wetlands with cultivated (sparse vegetation cover) catchments accumulated sediments at a rate about two times that of basins with dense grassland cover.

### Functional Capacity Index

The assessment model for calculating the functional capacity index (FCI) is as follows:

$$FCI = \sqrt{V_{SED} \times \frac{\left[ \frac{(V_{UPUSE} + V_{GRASSCONT} + V_{GRASSWIDTH})}{3} \right] + \left[ \frac{(V_{VEGCOMP} + (\text{Minimum of } V_{OUT}, V_{SUBOUT}))}{2} \right]}{2}}$$

In this model, the capacity of a prairie pothole wetland to retain particulates depends upon three characteristics, the ability of the depression to physically store sediment, the ability of sediment to reach the wetland, and the slowing of surface waters long enough to allow particulates to settle. In the first part, the  $V_{SED}$  variable indicates whether there is any capacity in the basin to trap additional sediment. If the depressional characteristic of the wetland is eliminated, there is no place for the sediment to be stored.

In the second part of the model,  $V_{UPUSE}$  and  $V_{GRASSCONT}$  and  $V_{GRASSWIDTH}$  represent the ability of the surrounding landscape to deliver or prevent particulates from reaching the wetland. For slopes < 15%, most sediment settling occurs within a 7.4 to 9 m wide buffer of grass (Dosskey, Schultz, and Isenhardt. 1997). These variables are partially compensatory and assumed to be independent and to contribute equally to the performance of the function. The variables are combined using an arithmetic mean which reduces the influence of lower subindices on the FCI (Smith and Wakeley 2001) which in this case is consistent with the assumption that these variables have less of an influence on the function. For example, the presence of a buffer will reduce the amount of sediment that actually reaches the wetland even if the  $V_{UPUSE}$  subindex is 0.0.

In the third part of the model,  $V_{VEGCOMP}$  and  $V_{OUT}$  reflect the ability of the wetland to reduce the velocity of the water moving into and through the wetland. These variables are partially compensatory and assumed to be independent and to contribute equally to the performance of the function. The variables are combined using an arithmetic mean which reduces the influence of lower subindices on the FCI (Smith and Wakeley 2001) which in this case is consistent with the assumption that these variables have less of an influence on the function. For example, even if the subindex for  $V_{OUT}$  is 0.0, the roughness contributed by plants will still retain some of the particulates.

In the aggregation equation  $V_{SED}$  is weighted more heavily by the use of a geometric mean. The logic for this is simple, if there is no depression left there is no place to store sediment and the "wetland" could actually become a source of sediment.

#### **Function 4: Remove, Convert, and Sequester Dissolved Substances**

##### Definition

Remove, Convert and Sequester Dissolved Substances is defined as the ability of a wetland to remove and sequester imported nutrients, contaminants, and other elements and compounds. The term "removal" is used to imply permanent loss of nutrients, contaminants, or other elements and compounds through or conversion by biogeochemical reactions. The term "sequestration" implies relatively long-term accumulation of elements and compounds such as by uptake and incorporation into long-lived perennial herbaceous biomass. Elements include macronutrients essential to plant growth (e.g., nitrogen, phosphorus, potassium, etc.) and other elements such as heavy metals (e.g. zinc, chromium, etc.) that can be toxic at high concentrations. Compounds include herbicides, pesticides and other imported materials. A potential independent, quantitative measure of this function is the amount of one or more imported elements and compounds removed or retained per unit area during a specified period of time (e.g., g/m<sup>2</sup>/yr).

##### Rationale for Selection of Function

The functioning of wetlands as interceptors of non-point source pollution is well documented (Johnston 1991). Elements and contaminants in surface and groundwater that come in contact with wetland soils and vegetation are either removed over the long term by sedimentation or are transformed into innocuous and biogeochemically inactive forms. There are several reviews on nutrient removal by wetlands, including those of Faulkner and Richardson (1989); and Johnston (1991). From the mid-1970s to the mid-1980s, much research and development effort was invested in utilizing wetlands as sites for tertiary treatment of wastewater. Much of this work is summarized in U.S. Environmental Protection Agency (1983); Godfrey et al. (1985); and Ewel and Odum (1984). Because of their location on the landscape, pothole wetlands are strategically located to process nutrients and contaminants before they can contribute to groundwater and/or surface water pollution (Crumpton and Baker 1993). Jones, Borofka, and Bachmann (1976) showed that even a slight increase in the percentage of wetlands in an agricultural watershed reduced the amount of nitrate loads of streams leaving the watershed. Studies of natural wetlands receiving cropland runoff have shown a nitrate nitrogen removal rate as high as 90 % (Baker 1992).

The primary benefit of this function is that the removal, conversion, and sequestration of dissolved substances by pothole wetlands reduce the load of nutrients and pollutants in groundwater and in any surface water leaving the wetland. This translates into better water quality and aquatic habitat in adjacent wetlands and down gradient streams and lakes.

##### Characteristics and Processes that Influence the Function

There are two categories of characteristics and processes that influence the capacity of a pothole wetland to remove, convert and sequester dissolved substances. The first deals with the mechanisms by which the elements and compounds are transported to the wetland, and the second deals with the structural components and biogeochemical processes involved in the function.

For rapid assessment a very broad approach has been taken to both the elements and compounds of interest and the mechanisms by which they are removed. This is in contrast to most of the research on the topic that is conducted on one element or mechanism at a time. Elements and compounds can enter the wetland environment via overland flow (i.e. in water and / or attached to sediment), aeolian snow-soil (Adomaitis, Kantrud, and Shoesmith 1967), wind-born dust, airborne drift or direct over-spray, and/or precipitation (Goldsborough and Crumpton 1998). Pothole wetlands may be especially subject to contamination by surface runoff because they occur in landscape positions that receive and/or concentrate runoff. Sequestration of imported elements and compounds occurs through exposure to solar irradiance for pesticide photolysis (Goldsborough and Crumpton 1998), adsorption, sedimentation, microbial biodegradation, denitrification, burial, uptake and incorporation into perennial biomass, and similar processes (Brinson et al. 1995).

Nitrogen and phosphorus are removed from incoming water in very different ways because the former is part of a gaseous biogeochemical cycle and the latter a sedimentary cycle (Schlesinger 1997). The major reactions that result in the removal of nitrogen from the wetland system are microbially mediated nitrification-denitrification reactions (Reddy and Patrick 1984). For phosphorous, plant uptake and interaction with the solid phase P components are the major removal processes (Mitsch et al. 1995). Microbial reactions generally play a smaller role in the storage of phosphorous but can play a significant role in its release from wetlands (Masscheleyn and Patrick 1993). The dissipation of pesticides in wetlands is less understood and is complicated by the large variety of pesticide compounds (Goldsborough and Crumpton 1998). Generally, research indicates that pesticide contaminants of surface and groundwater disappear rapidly from wetland waters, primarily as a result of adsorption by decomposing litter and the soil organic fraction (Huckins, Petty, and England 1986; Matter 1993; Crumpton et al. 1994). Wetlands are capable of trace metal removal (Masscheleyn and Patrick 1993), although the information on the effectiveness to remove these elements is incomplete. The three major mechanisms are: binding to soils, and soluble organics; precipitation as insoluble salts, principally sulfides and oxyhydroxides; and uptake by plants, including algae, and by bacteria (Kadlec and Knight 1996).

Nitrogen exists in many forms in wetland water columns and substrates, and has a complex cycle. Nitrogen is removed largely by four processes (Reddy and Patrick 1984), some of which are microbial: 1) uptake by plants, 2) immobilization by microorganisms into microbial cells during the decomposition of plant material, 3) adsorption of ammonium nitrogen onto the organic matter and the clay cation exchange complex and 4) most importantly, mineralization-nitrification-denitrification reactions. Within soils, two major conversion routes are dominant. Nitrification is the biological oxidation of reduced organic or inorganic N forms, usually  $\text{NH}_4^+$  to more oxidized forms, especially  $\text{NO}_3^-$ . The second, denitrification, transforms nitrate ( $\text{NO}_3^-$ ), which releases nitrogen gases ( $\text{N}_2\text{O}$  and  $\text{N}_2$ ) to the atmosphere. It is the coupling of aerobic (nitrification) and anaerobic (denitrification) reactions that allow wetlands to function most effectively to "remove" nitrogen from the ecosystem. In contrast to deeper aquatic systems, the shallow water sediment interface (Engler and Patrick 1974), root rhizospheres (Reddy, Patrick, and Lindau 1989) and alternating dry and inundated conditions of wetlands favor nitrification - denitrification reactions (Ponnamperuma 1972). This is the reason that the conversion of shallow, more seasonal type, wetlands to deeper, more permanent type, wetlands actually decreases many of the microbially mediated biogeochemical functions. Denitrification is dependent upon amount of organic carbon (Pastor et al. 1984), soil drainage (Groffman and Hanson 1997), soil redox potentials (Merrill and Zak 1992; Olness et. al. 1997), vegetation structure (Rose and Crumpton 1996), detritus (Howard-Williams and Howard-Williams 1978), and most of all, nitrogen loading rates (Crumpton and Baker 1993; Isenhardt 1992). Studies have

shown that nitrogen loading dramatically increases denitrification and wetlands may be nitrogen limited systems (Crumpton and Goldsborough 1998).

Phosphorus is removed from the water column in wetlands through plant uptake, immobilization by microorganisms into microbial cells during decomposition of plant material, adsorption of orthophosphate onto clay and oxyhydroxide surfaces and precipitation with cations such as calcium, magnesium and iron (Patrick 1992; Mitsch et al. 1995). The best long-term removal process is uptake by growing plants, and the storage of plant remains as peat or removal of plant material by harvest (Patrick 1992). There is a limit to the amount of phosphorus that can be adsorbed because adsorption sites can become saturated with phosphorus. Normally, most phosphorus is associated with particulate materials that are removed from the water column as sediments settle. Annual net uptake of phosphorus by growing vegetation, although significant, usually represents a small quantity relative to the soil/sediment sinks of phosphorus (Brinson 1985). Organic matter can also have high adsorptive capacity for compounds like phosphorus and heavy metals.

A major mechanism that contributes to removal of elements and compounds from water entering a wetland is reduction. Denitrification will not occur unless the soil is anaerobic and the redox potential falls below a certain level. In addition, sulfate is reduced to sulfide that then reacts with metal cations to form insoluble metal sulfides such as CuS, FeS, PbS, and others.

Heavy metals can be sequestered from incoming waters by adsorption onto the charged surfaces (functional groups) of clay minerals, by specific adsorption onto Fe and Al oxide minerals, by chemical precipitation as insoluble sulfide compounds, or by plant uptake (Kadlec and Knight 1996). These processes, other than plant uptake, are often controlled by the redox status of the soil (Masscheleyn and Patrick 1993). This function (Function 4) is focused on the chemical portion of the biogeochemical cycle, Function 3 (Retention of Particulates) focuses on the physical (geo) part of the cycle.

The variables of this function reflect land use and the biotic and abiotic components of the PPR ecosystem. Land use activities impact the elements and compounds entering the system and the natural removal and retention processes of these elements and compounds. The related variables are grassland width, grassland continuity, upland land use, and sediment. Biotic components remove elements and compounds through plant growth and decay. Rates of decomposition are slow enough to sequester or remove nutrients within the wetland. The related variable is vegetation composition. Abiotic components assist the reduction and oxidation processes that biogeochemically sequester elements and compounds. The related variables are wetland outlet, subsurface outlet, source area of flow, and soil organic matter.

### Functional Capacity Index

The assessment model for the function “Remove, Convert and Sequester Dissolved Substances is:

$$FCI = \sqrt{(\text{Minimum of } V_{OUT}, V_{SUBOUT}) \times \frac{\left[ \frac{(V_{GRASSWIDTH} + V_{GRASSCONT})}{2} \right] + \left[ \frac{(V_{SOURCE} + V_{UPUSE} + V_{SED})}{3} \right] + \left[ \frac{(V_{VEGCOMP} + V_{SOM})}{2} \right]}{3}}$$

In this model, the capacity of a depressional wetland to remove, convert and sequester dissolved substances is made up of three parts. The first focuses on maintaining a wet anaerobic environment in the wetland. The lesser of  $V_{OUT}$  or  $V_{SUBOUT}$  is used because the degree of wetness is the major driver in maintaining this biochemical function. The second portion of the model deals with the mechanisms by which the elements and compounds are transported to the wetland and is represented by the variables  $V_{GRASSWIDTH}$ ,  $V_{GRASSCONT}$ ,  $V_{SOURCE}$ ,  $V_{UPUSE}$  and  $V_{SED}$ . The five variables are equally independent. The third part deals with the biogeochemical processes involved in the function and is represented by the variables  $V_{SOM}$  and  $V_{VEGCOMP}$ . The two variables are partially compensatory based on the assumption that they are independent and contribute equally to performance of the function.

The second two parts of the model are averaged because the variables are considered to be interdependent and equally important. Therefore, a characteristic level of removing, converting and sequestering will not be achieved if mechanisms and processes are reduced. An arithmetic, rather than geometric, mean is used because it may be possible under certain circumstances for some variable subindices to drop to 0.0 for a short time. This would not result in the function being eliminated. A geometric mean is used for the subindices that are the indicators of anaerobic conditions ( $V_{SUBOUT}$  or  $V_{OUT}$ ) because without maintaining anaerobic conditions the functional capacity of a wetland is dramatically diminished. The primary mechanism for transforming many of the elements and compounds is based upon the presence of water (i.e. anaerobic conditions).

## **Function 5: Plant Community Resilience and Carbon Cycling**

### **Definition**

Plant Community Resilience and Carbon Cycling is defined as the ability of a pothole wetland to sustain native plant community patterns and rates of processes in response to the variability inherent in its natural disturbance regimes. Plant communities develop and respond to changing environmental conditions including soil condition, hydrology cycles, wetland land use, and land use within the catchment. Even when not influenced by human activities, ecosystems show a high degree of variability, at different temporal and spatial scales, in diversity, structure, and function. Plant community sustainability also requires the maintenance of plant community properties such as seed dispersal, vegetative propagule production, plant densities, and growth rates that permit response to variation in climate and disturbance. In assessing this function, one must consider the extant plant community as a response to previous hydrologic cycles and the synergistic effects of natural and anthropogenic disturbances.

A variety of approaches have been developed to describe and assess plant community characteristics that might be appropriately applied in developing independent measures of this function. These include quantitative measures based on vegetation composition and abundance such as similarity indices (Ludwig and Reynolds 1988), indirect multivariate techniques such as detrended correspondence analysis (Kent and Coker 1995), and techniques that employ both vegetation and environmental factors, such as canonical correlation analysis (ter Braak 1994). Whether descriptive, comparative, or multi-variate statistical analyses are used for vegetation characterization and determination of explanatory environmental variables, the goal of the assessment is to describe both the reference standard condition and deflection from the reference standard. Invasion by non-native plants or ruderal native species is an indication that this function has been diminished.

## Rationale for selecting the function

The ability to maintain plant community productivity and processes is important because of the contribution to biodiversity and the many attributes and processes of pothole wetlands that influence other functions. Emergent macrophytes represent the majority of biomass in primary productivity and subsequent loading into nutrient cycling processes. The macrophytic vegetation conducts the preponderant portion of the wetland's primary production (Richardson 1979), nutrient cycling (McKee and McKevlin 1993), contribution to annual detrital accumulations and soil development. The physical characteristics of the living and dead plants are closely related to ecosystem functions associated with abundance and diversity of animal species (Gregory et al. 1991). Macrophytic vegetation also provides most of the trophic support for secondary production (Crow and Macdonald 1978), whether that production is based on direct grazing of living plant biomass or whether the energy is shunted through the detrital-based food web. In addition to these trophic relationships, vegetation provides a structural component for fauna that depends on wetlands for fulfillment of some or all of their life cycle requirements. Vegetation patterns are likely to control major aspects of wetland biogeochemistry and trophic dynamics, and wetlands should be viewed as complex mosaics of habitats with distinct structural and functional characteristics (Rose and Crumpton, 1996). The structure and composition of the plant communities may also directly or indirectly influence floodwater retention, sediment retention, and surface-groundwater interaction at a local or regional scale.

## Characteristics and processes that influence the function

Disturbance maintains the current plant community or resets successional processes to different stages. Plant community dynamics are influenced by the type and timing of disturbance (whether recurrent or catastrophic). Disturbances initiating directional community change or maintenance of community dynamics include hydrological variation, herbivory, or fire. Wetland vegetation should not be considered as temporally static, but rather as changing in composition and characteristics over a hierarchy of temporal scales; annual cycles, multi-year life history cycles, and longer climatic cycles (van der Valk 2000). Wetland vegetation is an interactive component of ecosystem structure and function, operating both in response to the preceding disturbance- based driving mechanisms as well as a driving mechanism for other wetland functions (e.g., faunal habitat, primary productivity).

Both plant community response and driver mechanisms are influenced by human disturbance. Anthropogenically-induced changes in water movement, water quantity or quality, and sediment transport influences the ability to maintain characteristic plant communities and processes. Alterations to the disturbance regime outside of the "normal range of variation" alters ecosystem processes, which in turn alter their characteristic spatial and compositional attributes. Communities affected by human activity also exhibit reduced resistance to natural stressors (De Leo and Levin, 1997). The natural fluctuation of water levels is the most important driver of vegetational change in prairie wetlands. Anthropogenic alterations both within the catchment and the wetland basin as manifested by surface ditches, underground tiles, dugouts, impoundments and road construction alters hydro-dynamics and hence the wetlands' resilience in responding to change. Some wetland basins, although not directly drained, no longer hold water because of the effects of drainage elsewhere within the local hydrologic systems. This alteration of basins' recharge /discharge relationships can similarly contribute to "un-natural" variability in hydro-dynamics with decreased plant community resilience.

Conversion of the source catchment from low to high impact land uses causes movement of topsoil into wetland basins with potential increases in nutrients. Anthropogenic sedimentation potentially suppresses primary production and alters natural food chain interactions. Sedimentation has been shown to significantly reduce species richness, propagule emergence, and germination of wetland macrophytes (Gleason and Euliss 1998). Basins in poor-quality watersheds tended to have slightly fewer communities (Kantrud and Newton, 1996). Increasing nutrients are often associated with the invasion of exotic species. Increased sedimentation selects for monotypic stands of aggressive native species (e.g. *Typha* spp.) or invasive exotic species (*Phalaris arundinacea*).

Similarly, land use practices within the wetland can affect plant community composition, substrate and nutrient dynamics. The mechanical disturbance to a wetland by repeated cultivation affects all stages in the plant regeneration cycle, an important mechanism in the maintenance of plant species diversity and plant community processes (Grubb 1977; Euliss and Gleason, 1998). Such disturbances may eliminate characteristic normal emergent phase -wet phase- dry phase community dynamics, thereby allowing rapidly maturing annuals and relatively short, deep-rooted perennials more characteristic of the cropland drawdown and cropland tillage phases conditions to persist. Development of monotypic stands of macrophytes may effectively remove some of the variation in decomposer organisms that could act to maintain or increase vegetation heterogeneity (Kantrud 1986). Buildup of litter in monotypic stands may also result in altered rates of decomposition (Kantrud, Millar, and van der Valk 1989). Cultivation of various emergent wet-meadow and shallow-marsh communities during dry years creates coarse-grained vegetation mosaics with fewer communities (Kantrud and Newton, 1996).

In addition to cultivation, wetland vegetation also responds to “idle” conditions, haying, burning and grazing. Characteristic dominant species are often associated with each land use type. Fulton, Richardson, and Barker (1986) provided a listing of common emergent species response to various intensities of grazing, mowing and burning. Species were categorized as present under a given land use type, or decreasing or increasing in abundance in response to the land use. Stewart and Kantrud (1972) and Kantrud (1989a) provide a listing of common dominants associated with varying land use practices. Woody plants can invade idle wetlands, especially in formerly disturbed wet-meadow zones (Kantrud and Newton, 1996). The effects of grazing on wetland plant communities vary with timing, frequency and intensity. Both compositional and structural attributes may change in response to grazing. Unless unusually severe, grazing can result in greater plant species diversity, increased vegetation/open water interspersions, and sharper boundaries among plant communities (Bakker and Ruyter 1981). Long-term overgrazing can reduce the wet meadow zones to bare soil, affect the height and density of wetland vegetation, and may cause a decrease in primary production.

To assess this function, vegetation composition and environmental factors known to influence vegetation establishment and regeneration need to be evaluated. Also, human disturbances that mimic or simulate natural disturbances are less likely to threaten plant community integrity than are disturbances radically different from the natural disturbance regime (Noss 1995).

## Functional Capacity Index

The assessment model for calculating the functional capacity index (FCI) is as follows:

$$FCI = \sqrt{\left( \text{Minimum of } V_{OUT}, V_{SUBOUT} \right) \times \frac{\left[ \frac{(V_{UPUSE} + V_{GRASSCONT} + V_{GRASSWIDTH})}{3} \right] + \left[ \frac{(V_{SED} + V_{SOM})}{2} \right] + V_{VEGCOMP}}{3}$$

In the model, the lesser of  $V_{OUT}$  or  $V_{SUBOUT}$  is used because hydrodynamics is the major driver in plant community processes and subsequent responses.  $V_{UPUSE}$  indicates the condition of the catchment and this is averaged with  $V_{GRASSCONT}$  and  $V_{GRASSWIDTH}$ . This provides an indication of the immediate area surrounding the wetland, which will potentially affect the inputs of sediment or pollutants. Although  $V_{UPUSE}$ ,  $V_{GRASSCONT}$ , and  $V_{GRASSWIDTH}$  variables are related as source input areas, decreasing any of these variables is capable of diminishing this function.  $V_{SED}$  is then averaged with  $V_{SOM}$ .  $V_{SED}$  is the amount of sediment that has accumulated within the wetland and is used in this assessment model primarily to represent the assessment wetland as a sink for pollutants. Secondly, accelerated sediment inputs can reduce wetland volume, bury seed banks and alter characteristic vegetation dynamics and zonation.  $V_{SOM}$  represents inputs and availability of nutrients for carbon cycling.  $V_{VEGCOMP}$  is the most direct indication of how similar the plant community is to the reference standard conditions.  $V_{VEGCOMP}$  was, therefore, given a higher weighting within the assessment model.

## Function 6: Provide Faunal Habitat

### Definition

The function Provide Faunal Habitat is defined as the ability of a prairie pothole to support aquatic and terrestrial vertebrate/ invertebrate populations during some or part of their life cycle. Prairie wetland fauna have high variability in spatial and/or temporal use of wetlands and the surrounding landscape. Wildlife species diversity is generally highest when the wetland is structurally complex (Weller 1987). No single species, or species guild, can serve as a definitive, all-inclusive indicator of wetland habitat functions or carrying capacity (Weller 1988).

Habitat provided by wetlands and the landscape matrix changes between years and within seasons in response to natural or anthropogenic disturbance regimes. Given this variability, long term surveys of faunal diversity and abundance would be required to adequately assess the faunal function. These surveys would be more appropriate as an independent, quantitative verification of this function. Extensive surveys for HGM rapid assessment applications are impractical. Instead, structural and compositional multi-scale metrics that are less subject to these fluctuations are assessed. Emphasis is on the capacity of the wetland to maintain the habitats/resources necessary for characteristic faunal diversity and abundance.

Potential independent, quantitative measures of this function are species inventory approaches, with data analysis usually employing comparisons between sites using similarity indices (Odum 1950; Sorenson 1948). Another independent measure would be Habitat Evaluation Procedures (U.S. Fish and Wildlife Service, 1980). For biodiversity considerations at the landscape scale, waterfowl recruitment models (Reynolds, Cohan, and Johnson 1996; Cowardin, Shaffer, and Arnold 1995) or models assessing patch dynamics can be used (Forman and Godron 1986; Jongman et al. 1996).

## Rationale for selecting the function

It is generally recognized that most macrophyte production eventually ends up as detritus (Davis and van der Valk 1978b). Invertebrates are a critical link between the primary production / detrital resources of the system and the higher order consumers (Murkin and Wrubleski 1988; Driver, Sugden, and Kovach 1974). Specifically, invertebrate fauna: 1) process organic matter and are often major contributors to decomposition, 2) play an essential role in nutrient cycling, and, 3) provide important conduits of trophic support for higher level consumers through secondary production (Euliss, Mushet, and Wrubleski 1999). The abundant production of detritus may be the most important source of nutrients and energy for the invertebrates in wetland habitats and subsequent exploitation by higher order consumers (Batt et al. 1989; Murkin 1989).

Wetlands should be viewed as complex mosaics of habitats with distinct structural and functional characteristics (Rose and Crumpton, 1996). Vertebrate species utilizing wetlands of the Prairie Pothole Region respond to hydro-dynamics, vegetation composition and structure, and proximity to other habitats. A full range of habitat conditions is provided for wide-ranging or migratory animals, ecological generalists that possess the necessary adaptations to tolerate environmental extremes, and selected endemic species requiring specialized habitats. Populations also require exchange of genetic material between meta-populations to maintain long-term viability.

## Characteristics and processes that influence the function

Northern prairie wetlands have been greatly altered by human-induced changes that include drainage, alteration of catchments, accelerated sedimentation, suppression of fire, the removal or alteration of natural grazing patterns, and the introduction of exotic species. These alterations have often resulted in a more static system and a subsequent reduction in habitat diversity.

Increases in water level fluctuations or accelerated sedimentation due to tillage may ultimately affect the composition of a wetland's flora and fauna. Sediments may bury invertebrate egg banks that are important for maintenance and cycling of biotic communities during wet/dry cycles (Gleason et al. 2002). As vegetation controls major aspects of wetland biogeochemistry and trophic dynamics (Rose and Crumpton, 1996), any anthropogenic influences affecting vegetation pattern and composition will also impact food chain dynamics.

Leibowitz and Vining (2003) noted that intermittent surface-water connections between depressional wetlands could affect biodiversity or population dynamics through the transport of individuals or reproductive bodies. However, local wetland drainage and road construction may have altered historical connectivity. Wetlands bisected or in close proximity to highways and roads fragment the landscape and have an immediate impact on wildlife mortality (O'Neill et al. 1997). Localized fragmentation limits the ability of organisms to move within and between wetlands. Trombulak and Frissell (2000) reviewed the scientific literature on the ecological effects of roads and found support for the general conclusion that they are associated with negative effects on biotic integrity in both terrestrial and aquatic ecosystems.

Within the Prairie Pothole Region, wetland drainage has focused mostly on shallow temporary and seasonal wetlands within agricultural fields. The result has been a shift in the proportion of available wetland classes and alteration of hydrologic regimes of many non-drained wetlands. Small wetlands are critical components of the surrounding landscape that

influence habitat suitability of larger wetlands (Naugle et al., 2003). The destruction of even small depressional wetlands can lower the water table through an area and change hydrologic functions of other wetlands (Winter 1988). These include local, intermediate, and regional connections and hydrologic groundwater dependencies that maintain water storage and/or diversity of wetlands.

Landscape scale characteristics affect the ability of a wetland to provide faunal habitat. Analyses by Naugle et al. (2003) indicated that habitat suitability for some species (e.g., Virginia rail, pied-billed grebe) is related to local vegetation conditions within wetlands, while suitability for others (e.g., northern pintail, black tern) is related to landscape structure at larger scales. As a result, unfragmented wetland complexes embedded within upland grasslands provide habitat for more species than isolated wetlands in agricultural lands. Marsh isolation has been shown to reduce bird densities (Brown and Dinsmore 1991). Lehtinen, Galatowitsch, and Tester (1999) examined habitat loss and fragmentation, as well as selected within-wetland conditions potentially affecting amphibian assemblages. Amphibian species richness was lower with increased wetland isolation and road density.

The decline of many species has been linked directly to habitat loss and fragmentation (Schumaker, 1996). Species most vulnerable to loss of small wetlands are those that exploit resources over broad spatial scales (Naugle et al, 2003). Habitat fragmentation exacerbates the problem of habitat loss for both grassland and wetland birds. According to Johnson (2001), remaining patches of grasslands and wetlands may be too small, too isolated, and too influenced by edge effects to maintain viable populations of some breeding birds. Greenwood et al. (1995) found that duck nest success in the Canadian PPR was negatively correlated with the amount of cropland present.

Continuity of vegetation, connectivity of specific vegetation types, the presence and extent of corridors between upland/wetland habitats, and corridors between wetlands all have direct bearing on the movement and behavior of animals that use wetlands (Sedell et al. 1990). Such connections between habitats help maintain higher animal and plant diversity across the landscape than would be the case if habitats were more isolated from one another (Brinson et al. 1995). The functional redundancy of diverse hydrogeomorphic classes on the landscape plays a fundamental role in maintaining an ecosystem's ability to respond to changes and disturbance by providing resilience from stresses and catastrophes (Levin 1995, 1997). Fragmentation of landscapes effectively reduces the size of habitat units as well as diminishing habitat continuity.

## Functional Capacity Index

The assessment model for calculating the functional capacity index (FCI) is as follows:

$$FCI = \sqrt{\left( \text{Minimum of } V_{OUT}, V_{SUBOUT} \right) \times \left[ \frac{(V_{UPUSE} + V_{SED})}{2} \right] + \left[ \frac{(V_{GRASSCONT} + V_{GRASSWIDTH} + V_{EDGE} + V_{WETPROX})}{4} \right] + V_{VEGCOMP}} \quad 3$$

Hydrology ( $V_{OUT}$ ,  $V_{SUBOUT}$ ) was given the greatest weight in the equation. The alteration of a wetland's hydroperiod will result in the greatest impact to wetland dynamics, subsequent

plant community responses and ultimately effect habitat selection/ utilization by fauna. Next in the equation are the variables  $V_{UPUSE}$  and  $V_{SED}$ .  $V_{UPUSE}$ , the land use/land cover of the catchment, affects sedimentation rates and hydro-dynamics within the wetland. Additionally, the condition of the surrounding upland influences faunal movement between wetlands and provides cover for wetland dependent wildlife.  $V_{SED}$  is measured in the wetland and is a response to  $V_{UPUSE}$ . These two variables are averaged in the assessment model. Excessive sediment can bury plants, seed banks, and invertebrates (Gleason and Euliss 1998; Luo et al. 1997), thereby altering trophic relationships. Accelerated sedimentation leads to wetland volumetric reductions and a less diverse wetland bottom topography. The establishment and spread of invasive species such as reed canary grass, cattail, and river bulrush is selected for in these instances. Monotypic stands of these species develop, further reducing faunal utilization.

The variables in the equation directly related to vegetation structure and composition as they influence fauna are  $V_{GRASSCONT}$ ,  $V_{GRASSWIDTH}$ ,  $V_{EDGE}$ ,  $V_{WETPROX}$ , and  $V_{VEGCOMP}$ . The continuity and extent of grassland cover around a wetland influences habitat for fauna, provides movement corridors, and influences the vegetative structure and composition of the wetland by serving as a seed bank in these mesic, ecotonal areas.  $V_{GRASSCONT}$ ,  $V_{GRASSWIDTH}$ ,  $V_{WETPROX}$  and  $V_{EDGE}$  are averaged in the assessment model. These four variables in combination provide an indication of habitat inter-connectivity at a local scale. The composition of the wetland vegetation ( $V_{VEGCOMP}$ ), although subject to cyclic changes, has a direct effect on faunal habitat and can also provide a measure of long-term habitat suitability.

Important to fauna is the spatial relationship of an individual wetland with respect to adjacent wetlands within a “complex”. Hubbard (1988) , defined a wetland complex as an assemblage of individual wetland basins in relatively close proximity to each other.

For projects involving multiple wetlands over a larger landscape area,

$$\sqrt{V_{HABFRAG} \times \left[ \frac{(V_{BASINS} + V_{WETAREA})}{2} \right]}$$

in this form, is substituted for;  $\left[ \frac{(V_{GRASSCONT} + V_{GRASSWIDTH} + V_{EDGE} + V_{WETPROX})}{4} \right]$  in the preceding assessment model. The assessment model for multiple projects would then be:

$$FCI = \sqrt{\left( \text{Minimum of } V_{OUT}, V_{SUBOUT} \right) \times \frac{\left[ \frac{(V_{UPUSE} + V_{SED})}{2} \right] + \sqrt{V_{HABFRAG} \times \left[ \frac{(V_{BASINS} + V_{WETAREA})}{2} \right]}{3} + V_{VEGCOMP}}$$

$V_{OUT}$ ,  $V_{UPUSE}$ ,  $V_{SED}$ , and  $V_{VEGCOMP}$  are used in the landscape assessment option to maintain the linkage of the assessment wetland to the surrounding ecosystem.

## 5 Assessment Protocol

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### Overview

In previous sections of this Guidebook, we provide: a) background information on the HGM Approach, b) wetland variables that are indicators of the level of function, c) the assessment models (FCI's) consisting of those indicator variables, and d) how those indicators and models are used to describe level of function. This chapter provides the specific protocols that should be followed to conduct a functional assessment of Prairie Pothole depressional wetlands. These protocols are designed for, and will generally be used within the context of the Clean Water Act (CWA) Section 404 permit review process and for determining minimal effects under the Food Security Act (FSA). They may also be used for other wetland management goals or objectives (e.g., monitoring, evaluation) that require measures of function.

The typical assessment scenario is a comparison of pre-project and post-project conditions in the wetland. In practical terms, this translates into a comparison of the functional capacity of the wetland assessment area (WAA) under both pre-project and post-project conditions with the subsequent determination of how FCI's have changed as a result of the project. Data for the pre-project assessment are collected under existing conditions at the project site, while data for the post-project assessment are normally based on the conditions that are expected to exist following proposed project impacts. A skeptical, conservative, and well-documented approach is required in defining post-project conditions.

This chapter discusses each of the tasks required to complete an assessment of Prairie Pothole depressional wetlands, including:

1. Define assessment objectives
2. Characterize the project area
3. Screen for red flags
4. Define the Wetland Assessment Area
5. Collect field data
6. Data entry and analysis
7. Apply the results of the assessment

### Define Assessment Objectives

Begin the assessment process by identifying the purpose for conducting the assessment. This can be as simple as stating, "The purpose of this assessment is to determine how the proposed project will impact wetland functions." Other potential objectives could be: (a) compare several wetlands as part of an alternatives analysis, (b) identify specific actions that can be taken to minimize project impacts, (c) document baseline conditions at the wetland site, (d) determine mitigation requirements, (e) determine mitigation success, or (f) determine the effects of a wetland management technique. Frequently, there will be multiple purposes identified for conducting the assessment. Defining the purpose(s) will facilitate communication and understanding between the people involved in conducting the assessment and will make the purpose(s) clear to other interested parties. In addition, it will help to establish the approach that is taken. The specific approach will vary to some degree, depending on

whether the project is a Section 404 permit review, an Advanced Identification (ADID), an FSA minimal effects determination, or some other scenario.

## Characterize the Project Area

Characterizing the project area involves describing the project area in terms of climate, geomorphic setting, hydrology, vegetation, soils, land use, proposed impacts, and any other characteristics and processes that have the potential to influence how wetlands at the project area perform functions. The characterization should be written and should be accompanied by maps and figures that show project area boundaries, jurisdictional wetlands, WAA, proposed impacts, roads, ditches, buildings, streams, soil types, plant communities, threatened or endangered species habitat, and other important features.

The following list identifies some information sources that will be useful in characterizing a project area.

- a) Aerial photographs or digital ortho-photos covering the wetland and surrounding landscape.
- b) Topographic and National Wetland Inventory maps (1:24000 scale) covering the wetland and the surrounding landscape with a 1.6 km radius.
- c) County Soil Survey
- d) Preceding five years of Farm Service Agency aerial compliance slides.
- e) Climatic records
- f) Farm Service Agency wetlands determination maps

## Screen for Red Flags

Red flags are features within, or in the vicinity of, the project area to which special recognition or protection has been assigned on the basis of statutory criteria (Table 14). Many red flag features, such as those based on national criteria or programs, are similar from region to region. Other red flag features are based on regional or local criteria. Screening for red flag features represents a pro-active attempt to determine if the wetlands or other natural resources in and around the project area require special consideration or attention that may preempt or postpone an assessment of wetland function. The assessment of wetland functions may not be necessary if the project is unlikely to occur as a result of a red flag feature.

<b>Table 14</b>	
<b>Red Flag Features and Respective Program/Agency Authority</b>	
<b>Red Flag Features</b>	<b>Authority<sup>1</sup></b>
Native Lands and areas protected under the American Indian Religious Freedom Act	A
Hazardous waste sites identified under CERCLA or RCRA	I
Areas protected by a Coastal Zone Management Plan	E
Areas providing Critical Habitat for Species of Special Concern	B, C, F
Areas covered under the Farmland Protection Act	K
Floodplains, floodways, or flood-prone areas	J
Areas with structures/artifacts of historic or archeological significance	G
Areas protected under the Land and Water Conservation Fund Act	K
Areas protected by the Marine Protection Research and Sanctuaries Act	B, D

National wildlife refuges and special management areas	C
Areas identified in the North American Waterfowl Management Plan	C, F
Areas identified as significant under the RAMSAR Treaty	H
Areas supporting rare or unique plant communities	C, H
Areas designated as Sole Source Groundwater Aquifers	I, L
Areas protected by the Safe Drinking Water Act	I, L
City, County, State, and National Parks	D, F, H, L
Areas supporting threatened or endangered species	B, C, F, H, I
Areas with unique geological features	H
Areas protected by the Wild and Scenic Rivers Act or Wilderness Act	D
<sup>1</sup> Program Authority / Agency A = Bureau of Indian Affairs B = National Marine Fisheries Service C = U.S. Fish and Wildlife Service D = National Park Service E = State Coastal Zone Office F = State Departments of Natural Resources, Fish and Game, etc. G = State Historic Preservation Office H = State Natural Heritage Offices I = U.S. Environmental Protection Agency J = Federal Emergency Management Administration K = National Resource Conservation Service L = Local Government Agencies	

For example, if a proposed project has the potential to impact a threatened or endangered species or habitat, an assessment of wetland functions may be unnecessary since the project may be denied or modified strictly on the impacts to threatened or endangered species or habitat.

## Define the Wetland Assessment Area

The WAA is an area of wetland within a project area that belongs to a single regional wetland subclass and is relatively homogeneous with respect to the site-specific criteria used to assess wetland functions (i.e., hydrologic regime, vegetation structure, topography, soils, seral stage, etc.). In most project areas, there will be just one WAA representing a single regional wetland subclass as illustrated in Figure 25. However, as the size and heterogeneity of the project area increases, it is possible that it will be necessary to define and assess multiple WAAs within a project area.

At least three situations necessitate defining and assessing multiple WAAs within a project area. The first situation exists when widely separated wetland patches of the same regional subclass occur in the project area (Figure 26). The second situation exists when more than one regional wetland subclass occurs within a project area (Figure 27). The third situation exists when a physically contiguous wetland area of the same regional subclass exhibits spatial heterogeneity with respect to hydrology, vegetation, soils, disturbance history, or other factors that translate into a significantly different value for one or

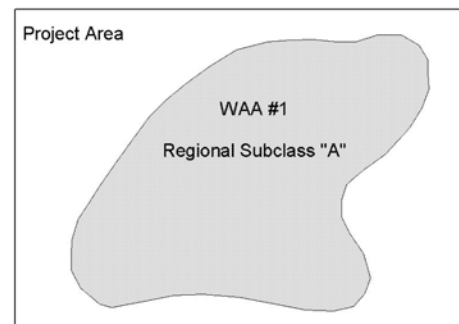


Figure 25. A single WAA within a project area

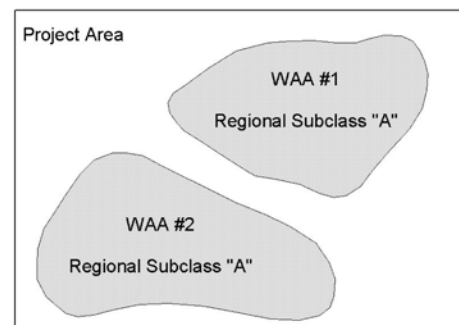


Figure 26. Spatially separated WAA from the same regional wetland project area.

more of the site-specific variable measures. These differences may be a result of natural variability or cultural alteration (e.g., farming, urban development, hydrologic alterations) (Figure 28). Designate each of these areas as a separate WAA and conduct a separate assessment on each area.

There are elements of subjectivity and practicality in determining what constitutes a “significant” difference in portions of the WAA. Field experience with the regional wetland subclass under consideration should provide the sense of the range of variability that typically occurs and the “common sense” necessary to make reasonable decisions about defining multiple WAAs. Splitting an area into many WAAs in a project area, based on relatively minor differences, will lead to a rapid increase in sampling and analysis requirements. In general, differences resulting from natural variability should not be used as a basis for dividing a contiguous wetland area into multiple WAA’s. However, zonation caused by different hydrologic regimes or disturbances caused by rare and destructive natural events should be used as a basis for defining WAA’s.

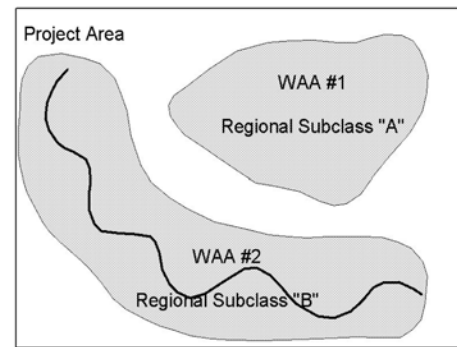


Figure 27. Spatially separated WAAs from different regional wetland subclasses within a project area.

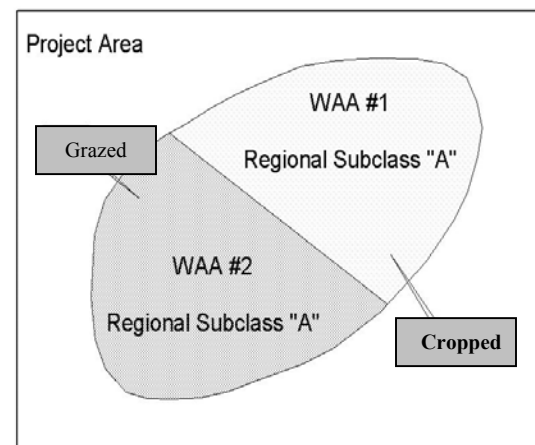


Figure 28. WAA defined based on differences in site specific characteristics.

## Collect Field Data

The following equipment is necessary to collect field data.

- a. Plant identification keys
- b. Soil sharpshooter shovel
- c. County Soil Survey
- d. Munsell color book and hydric soil indicator list (U.S. Department of Agriculture, NRCS 2002)
- e. 50-m distance measuring tape and meter sticks, stakes, and flagging.

Information and data about the variables used to assess the functions of Prairie Pothole depressional wetlands is collected at several different spatial scales. Information about landscape scale variables, such as land use, is collected using aerial photographs, maps, and field reconnaissance of the area surrounding the WAA. Subsequently, information about the WAA in general is collected during a walking reconnaissance of the WAA. Finally, detailed site-specific

information is collected using sample plots and transects at a number of representative locations throughout the WAA.

The exact number and location of these data collection points are dictated by the size and heterogeneity of the WAA. If the WAA is relatively small (i.e., less than 0.8 - 1.2 ha) and homogeneous with respect to the characteristics and processes that influence wetland function, then three or four sample points in representative locations are probably adequate to characterize the WAA. However, as the size and heterogeneity of the WAA increases, more sample plots are required to accurately represent the site.

As in defining the WAA, there is an element of subjectivity and practical limitations in determining the number of sample locations for collecting site-specific data. Experience has shown that the time required to complete an assessment at a several-hectare WAA is 2-4 hours. Training and experience will reduce the required time to the lower end of this range.

Data and information relating to the variables in this model should be collected according to methods and guidelines provided in Appendix B-2. Data should be recorded on the field forms also found in Appendix B. Be sure you have collected all on-site data needed in order to avoid a second follow-up site visit.

## Data Analysis

### Data Entry

Follow the assessment protocols given above to complete a wetland functional assessment using this Guidebook. It is critical that all data entries are made on the field forms provided with this Guidebook in Appendix B-2. This will greatly reduce confusion about what data need to be collected and will assist the user to prevent accidentally skipping over necessary field data while visiting the WAA. Much of the initial site characterization and map data will come from pre-existing databases, Internet sources (e.g., USGS, NRCS) or office source materials (e.g. NWI maps, County soil survey maps). The time necessary to collate these materials and analyze the maps and complete data entry of Landscape Scale variables from pre-existing databases is generally 2-3 hours. Collection of field data for a single Prairie Pothole wetland of moderate size and complexity will generally require two people 2-4 hours of field time to complete.

### Data Analysis

The primary objective of the HGM Approach to the Functional Assessment of Wetlands is the determination of Functional Capacity Indices (FCI), which when combined with area produces a Functional Capacity Unit (FCU), which in turn provides a basis for determination of impact and mitigation.

### Manual Determination of FCI

After completing the above protocols to collect all data and the completion of the field data forms found in Appendix B-2, fill out the Functional Capacity Index worksheet, provided in Appendix B-3.. The metric to variable subindex score relationships are based on the reference

wetland data set collected during the development of this Guidebook. The variable subindex scores are employed in the six Functional Capacity Index algorithms discussed and explained in chapters 4 and Appendix B-1 of this Guidebook. The Guidebook user can then determine, by hand calculation, the Functional Capacity Indices (FCI) of each function.

## Spreadsheet Determination of FCI

The data sheets are designed to assist the user enter the raw data collected from each site. The regression equations needed to calculate the variable subindex for each wetland function are already entered into this spreadsheet. The presence of these equations are designated by gray blocks within the spreadsheet (Figure 29). All other blocks indicate where the user is expected to enter their data. Instructions for each function are included in the spreadsheet and follow the format of the data sheets found in Appendix B-3. Each category, along with the corresponding variables, is located in one of worksheets. These worksheets are labeled by category. The functional capacity indices (FCI's) are also entered in the spreadsheet and can be found in the worksheet labeled 'FCI'. After each variable subindex has been calculated using the raw data entered by the user, the FCI's will be automatically computed.

<b>Vout</b>	
Wetland surface outlet. Elevation of wetland outlets, natural or constructed in relation to edge of the wetland and hydric soils; also, the volume of excavations/fill present within the hydric soil footprint of the wetland. Fixed bounce storage limit 3.28 feet (1 meter)	
Record:	
USER NOTE: Multiply feet by 0.305 to convert into meters.	
a) Historic Invert elevation in relation to wetland maximum depth:	
b) Present (or constructed) Invert elevation	
c) Elevation of the edge of the historic wetland:	
d) Elevation of a representative deepest portion of the wetland:	
e) Difference between c) and a)	
Difference between b) and d)	
Difference between a) and d)	
Difference between c) and b)	
If eval. PIT or fill, enter %vol of pit/fill versus wetland (ex. 25% = 25), otherwise enter 0	0
f) Ratio of the constructed elevation to the natural outlet elevation:	#DIV/0!
g) VARIABLE SUBINDEX SCORE for Vout:	#DIV/0!

Figure 29. Sample spreadsheet for data entry and FCI calculations.

## Apply the Results of the Assessment

Once the assessment and analysis phases are complete, the results can be used to compare the same wetland assessment area at different points in time, comparing different wetland assessment areas at the same point in time, comparing different alternatives to a project or comparing different hydrogeomorphic classes or subclasses as per Smith et al. (1995).

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